

The Adventures of
Archibald Higgins
(Anselme Lanturlu)

THE SILENCE BARRIER

Jean-Pierre
Petit

Now remember don't
make any waves!



The Association Knowledge without Borders, founded and chaired by Professor Jean-Pierre Petit, astrophysicist, aims at spreading scientific and technical knowledge in as many countries as possible and in as many languages as possible. To this end, all his popular scientific works, which cover a period of thirty years, and more particularly the illustrated albums he has created, are now freely accessible. Anyone is now free to duplicate the present file, either in digital form or in the form of printed copies and circulate these copies to libraries, within the context of schools or universities or associations whose aims would be the same as the association, provided that they do not derive any profit from this circulation and that they do not have any political, sectarian or confessional connotations. These pdf files may also be put on line in the computer networks of school and university libraries.



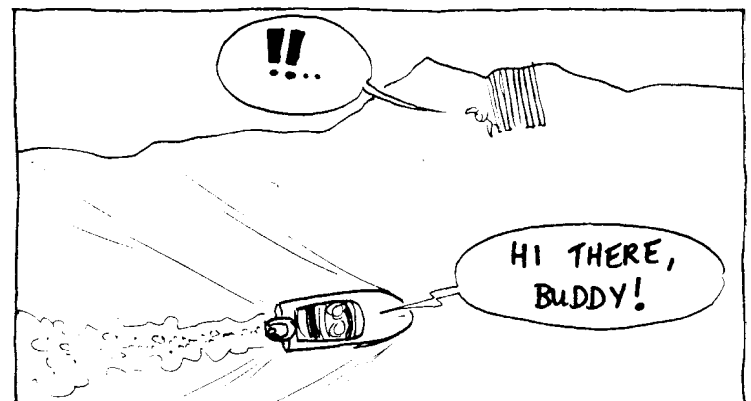
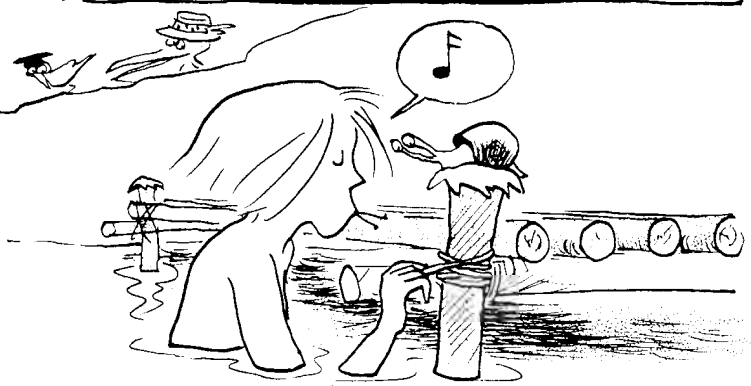
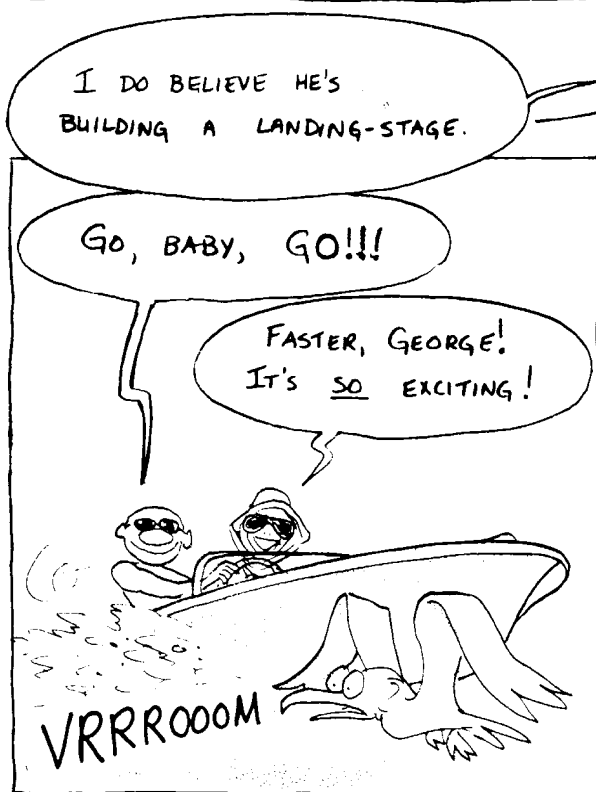
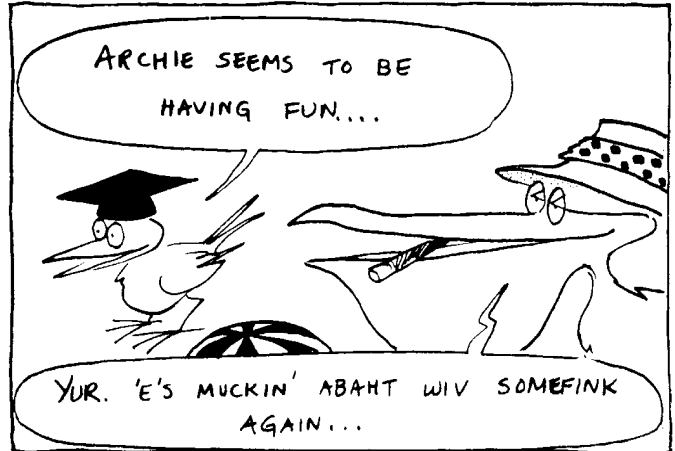
Jean-Pierre Petit intends to create numerous other works which will be accessible to a larger audience. Even illiterate people will be able to read them because the written parts will “speak” when the readers click on them. Thus it will be possible to use these works to support literacy schemes. Other albums will be “bilingual” in so far as it will be possible to switch from one language to another selected language with a mere click. Hence another tool made available to develop language skills.

Jean-Pierre Petit was born in 1937. He made his career in French research. He worked as a plasma physicist, he directed a computer science centre, he has created softwares, he has published hundreds of articles in scientific magazines, dealing with subjects ranging from fluid mechanics to theoretical cosmology. He has published about thirty books which have been translated in numerous languages.

The association can be contacted on the following internet site:

<http://savoir-sans-frontieres.com>

PROLOGUE



HIM AGAIN, WITH HIS
DUMB OLD BOAT!

VRRROOM

HE'S DEMOLISHED MY
LANDING-STAGE AGAIN.

I CHOSE A VERY SHELTERED
SPOT — I CAN'T UNDERSTAND
WHAT'S HAPPENING. EVERY TIME
HE GOES BY, THE WATER GETS
ALL CHURNED UP.

IT'S HIS BOW WAVE THAT'S
DOING ALL THE DAMAGE!

OH, THAT'S TEWWIBLE! THE MAN MUST BE
A WAVING LUNATIC!

SURFACE WAVES

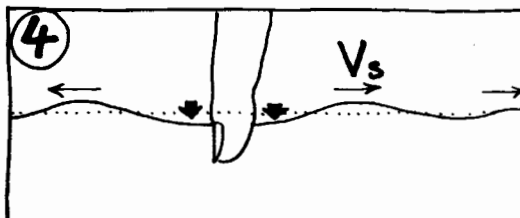
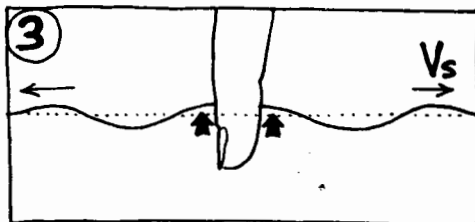
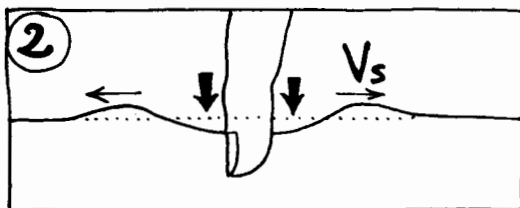
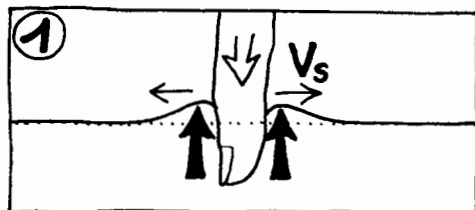
I THINK I'LL
CHUCK IT IN!...

CRIKEY, THAT MAKES
WAVES TOO. LET'S TAKE A
CLOSER LOOK.

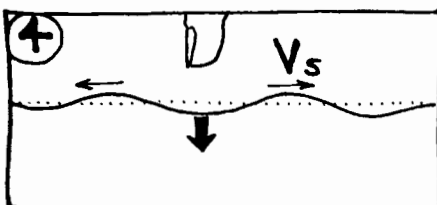
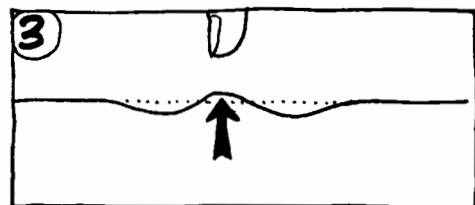
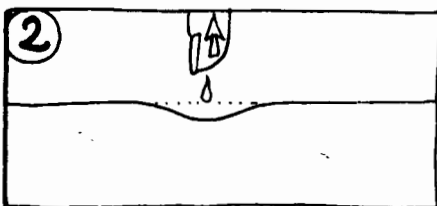
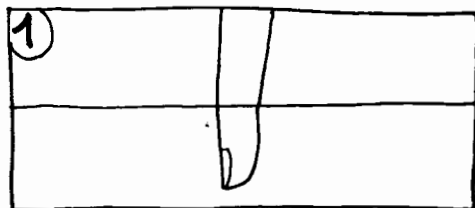
WOT'S TER LOOK AT?
IT AIN'T H'EXACTLY THE
BLINKIN' MAELSTROM.



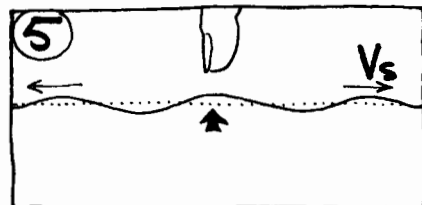
IF I STICK MY FINGER IN SUDDENLY, IT MAKES THE WATER NEARBY RISE TO FORM A SORT OF "SPARE TIRE." THE EXTRA THICKNESS LEADS TO OSCILLATIONS, WHICH ELIMINATE IT, FORMING CONCENTRIC SURFACE WAVES. THESE APPEAR TO TRAVEL AT A CONSTANT SPEED, WHICH I'LL CALL V_s ; AND AS THEY MOVE, THEY SLOWLY DIE AWAY.



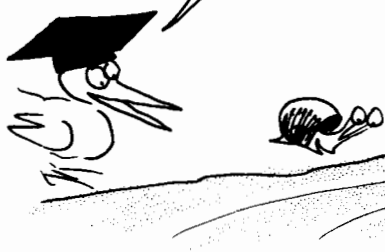
A SIMILAR EFFECT OCCURS IF, INSTEAD OF STICKING YOUR FINGER INTO THE WATER, YOU PULL IT OUT. AS A RESULT, THE LIQUID TENDS TOWARD A FREE PLANAR SURFACE.



COR! BARFROOM PHYSICS!



AS THE WAVES PROPAGATE, THEY SPREAD THEIR ENERGY OVER AN INCREASING AREA.



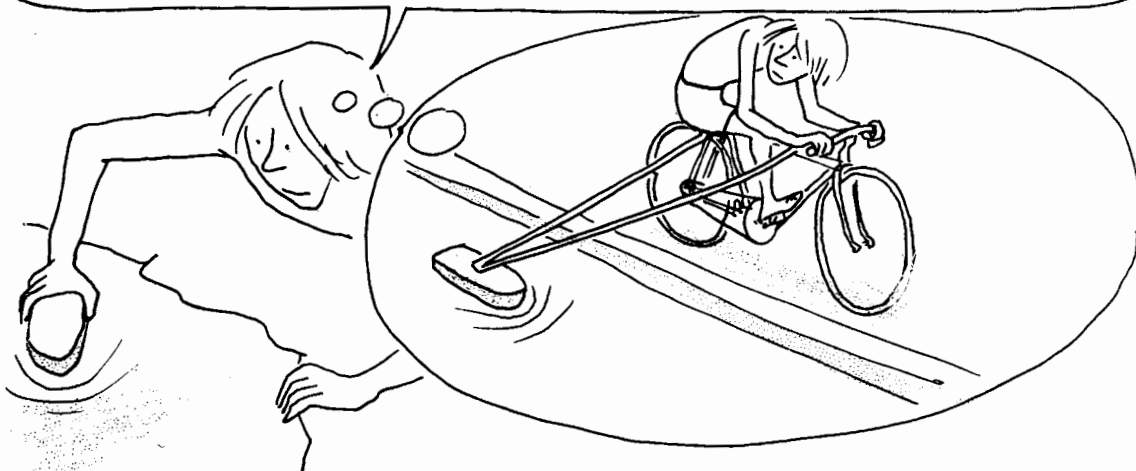
AND SINCE ENERGY IS CONSERVED, THE HEIGHT - OR AMPLITUDE - OF THE WAVES MUST PROGRESSIVELY DECREASE.

IF AN OBJECT MOVES ABOUT IN THE WATER, IT EMITS THIS TYPE OF WAVE, THEREBY ROUGHENING THE SURFACE OF THE WATER.

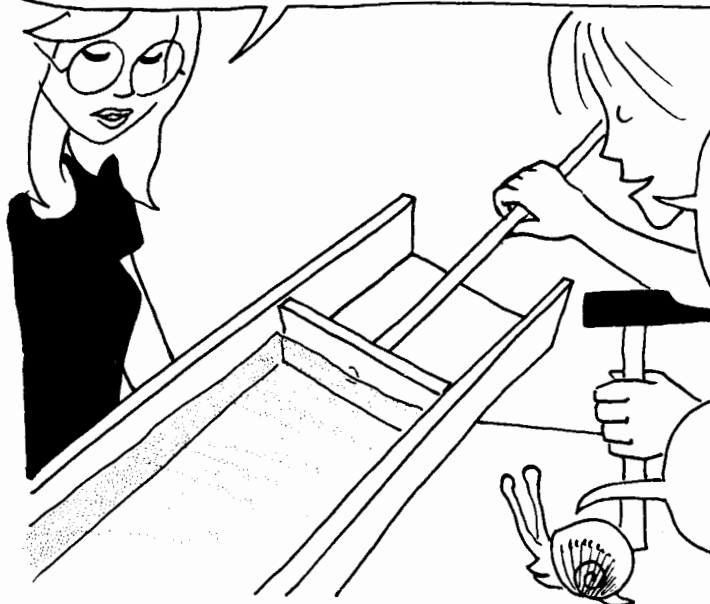


THE WAVES ACT ON THE FLUID. THEY START TO SEPARATE THE MOLECULES UPSTREAM, LETTING THE FLUID THERE MOVE TOWARDS THE OBJECT.

IF I WANT TO TAKE A LOOK AT THAT, I'D BETTER FIND A WAY OF FOLLOWING THE FLUID AS IT MOVES.



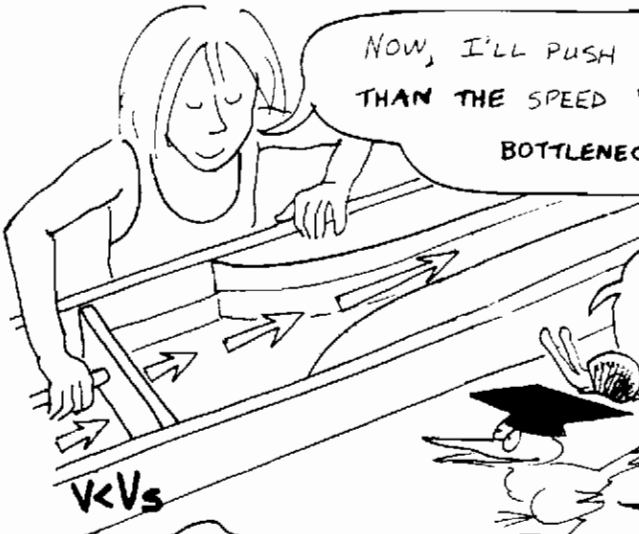
DON'T YOU THINK THAT'S A RATHER COMPLICATED SYSTEM? INSTEAD OF MOVING THE OBJECT, I SUGGEST YOU KEEP IT FIXED AND MOVE THE FLUID.



GOOD IDEA. HOW ABOUT THIS? IT'S A REDUCED-SCALE MODEL OF A CANAL, WITH A PLUNGER IN ONE END TO MOVE THE WATER.

IF YOU MOVE THE PLUNGER AT A SPEED V , THEN THE WATER NEARBY WILL ALSO MOVE AT SPEED V .

HUGONIOT'S RELATION



NOW, I'LL PUSH THE FLUID SLOWLY, AT A SPEED V LOWER THAN THE SPEED V_s OF SURFACE WAVES, INTO THIS BOTTLENECK.

IN THIS CONVERGENT REGION, THE WATER LEVEL IS VIRTUALLY CONSTANT AND THE FLUID ACCELERATES....

LIKE RAPIDS ON A RIVER.

COME ON, GUV - WE KNOW ABOUT ALL THAT, DON' WE? (*)

NOW I'LL PUSH THE WATER AT A SPEED V GREATER THAN THE SPEED V_s OF SURFACE WAVES.

WHAT A BORE!

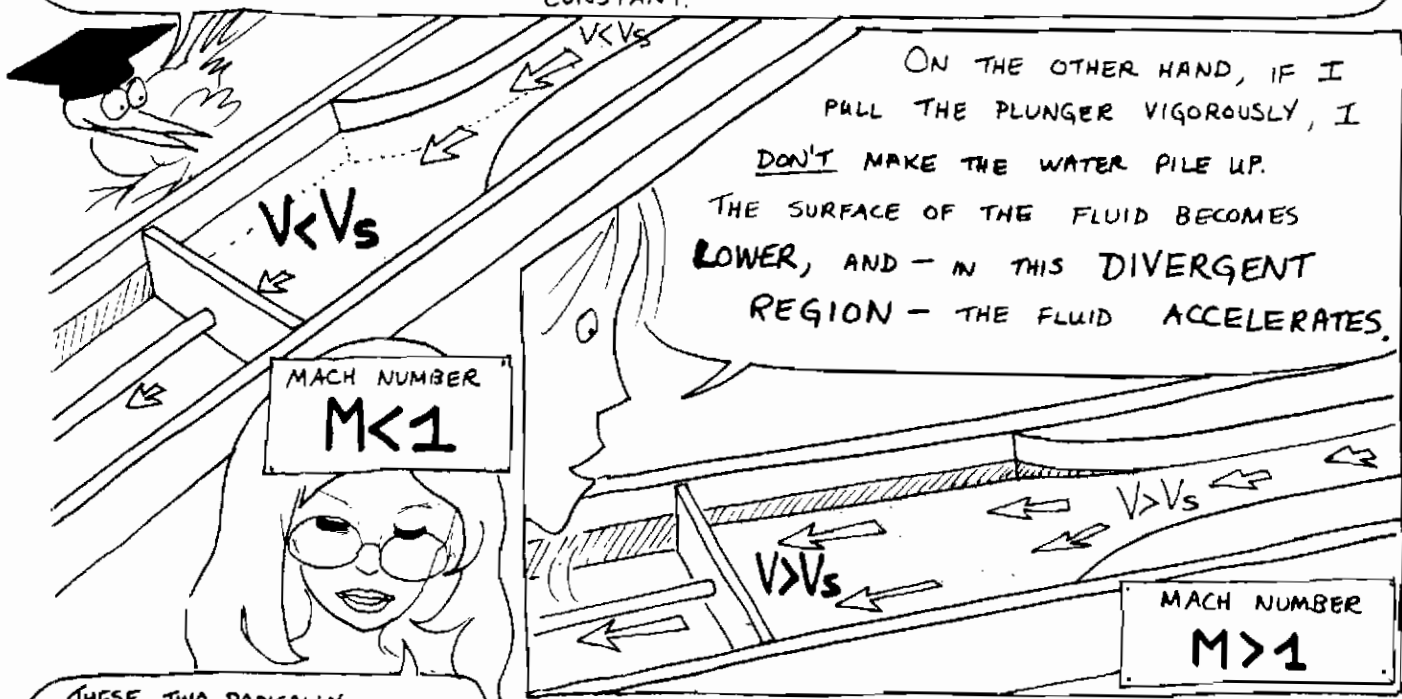
IT PILES UP AT THE ENTRANCE. THE WATER LEVEL RISES AND THE FLUID DECELERATES. THE EXACT OPPOSITE!

THE FLUID BEHAVES IN TWO TOTALLY DIFFERENT WAYS, DEPENDING ON WHETHER THE NUMBER $M = V/V_s$ (WHICH IS SIMILAR TO THE MACH NUMBER IN AERODYNAMICS) IS GREATER OR LESS THAN 1.

WHAT IF I PULL INSTEAD OF PUSH?

(*) SEE FLIGHT OF FANCY, SAME SERIES.

IF YOU PULL GENTLY AND THE SPEED V OF THE FLUID ALWAYS STAYS LESS THAN THE SPEED V_s OF SURFACE WAVES, THEN THE WATER DECELERATES IN THIS DIVERGENT REGION, AND THE HEIGHT OF THE WATER REMAINS VIRTUALLY CONSTANT.



THESE TWO RADICALLY

DIFFERENT KINDS OF BEHAVIOR ARE SUMMED UP IN THE THEOREM OF THE FRENCH PHYSICIST HUGONIOT:

Hugoniot	SPEED V LESS THAN THE SPEED V_s OF SURFACE WAVES (MACH NUMBER $M < 1$)	SPEED V GREATER THAN THE SPEED V_s OF SURFACE WAVES (MACH NUMBER $M > 1$)
IN A CONVERGENT REGION THE FLUID: THE LEVEL:	ACCELERATES STAYS CONSTANT	DECELERATES RISES
IN A DIVERGENT REGION THE FLUID: THE LEVEL:	DECELERATES STAYS CONSTANT	ACCELERATES DROPS

LEMME SEE... THE MORE YER GOES LESS QUICKLY, THE LESS THE SPEED GETS BIGGER... AT LEAST, MORE OR LESS... OR IS IT THE UVVER WAY ROUND?

HiHiHi...

PUFFFFFF! ALL THAT WATER'S TOO HEAVY FOR ME TO KEEP SHOVING IT AROUND WITH A PLUNGER. THERE'S GOT TO BE A BETTER WAY...

A STROKE OF GENIUS! BY ALTERING THE ANGLE OF THE CHANNEL I CAN CONTROL THE SPEED V AT WHICH THE WATER FLOWS.

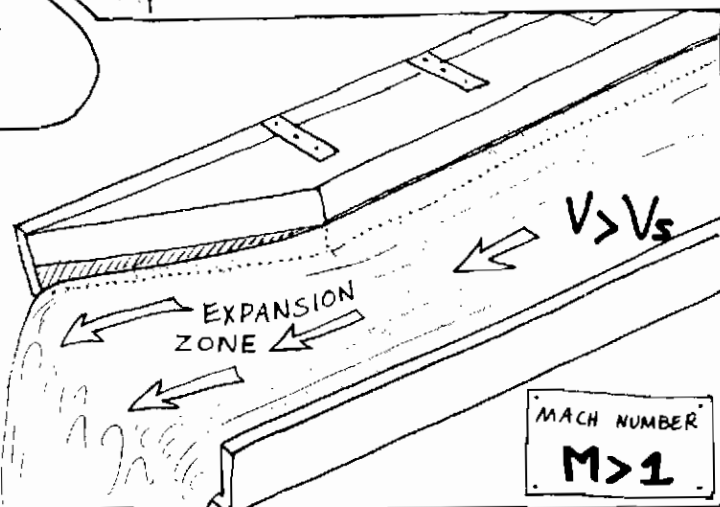
'ANG ON, MATE!
YER'V CHANGED
EVERYFINK!

NO, THE RESULT'S EXACTLY
THE SAME.

BACK TO THE
FLOW IN A DIVERGENT
REGION. BELOW THE CRITICAL
SPEED V_s , THE FLUID DECELERATES
AND THE WATER LEVEL IS NEARLY
CONSTANT.

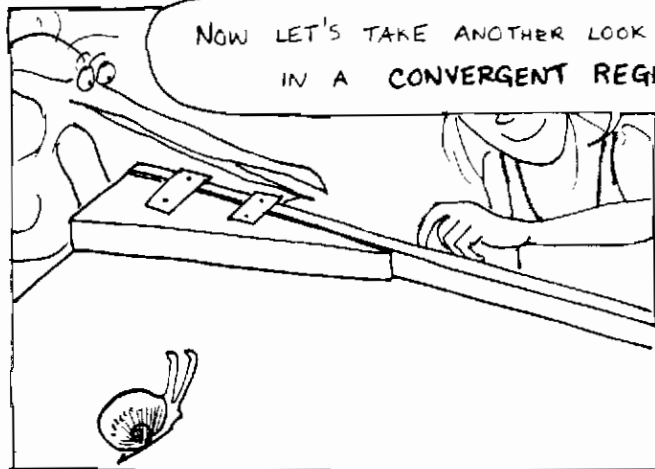
SPEED V
LESS THAN THE
SPEED V_s OF
SURFACE WAVES.
MACH NUMBER
 $M < 1$

IF THE FLUID ARRIVES
WITH A SPEED V GREATER
THAN THE CRITICAL SPEED V_s ,
THEN THE SURFACE BECOMES LOWER
AND THE WATER ACCELERATES.



WAVE FRONTS

NOW LET'S TAKE ANOTHER LOOK AT THE FLOW
IN A CONVERGENT REGION.

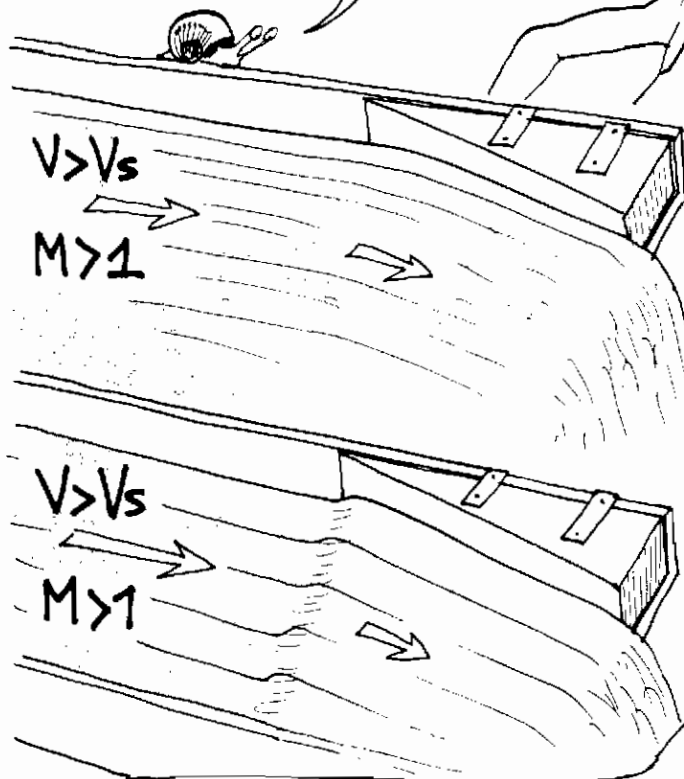


V LESS THAN V_s .
 M LESS THAN 1.

IF THE SPEED V OF THE FLUID IS LESS
THAN THE SPEED V_s (OF SURFACE WAVES), THEN
THE SPEED INCREASES AND THE LEVEL STAYS
CONSTANT.

BUT IF THE SPEED V
IS GREATER THAN V_s , THE
WATER LEVEL RISES AND THE
FLUID SLOWS DOWN.

C'MON, ARCHIE—
TILT IT A BIT
FURVER!



THE PARAMETERS DESCRIBING THE
FLUID CHANGE DRAMATICALLY WHERE IT
FORMS A BANK, OR A WAVE FRONT. THE WATER SLOWS DOWN AND THE
LEVEL RISES.

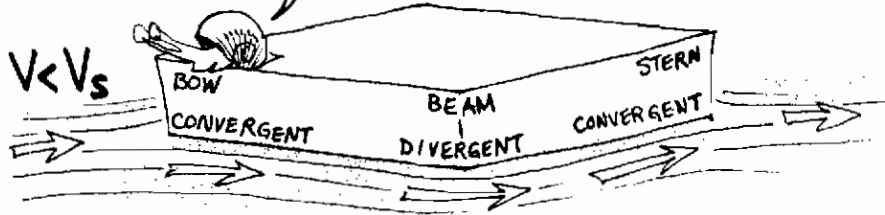
FLOW ROUND A CONTOUR



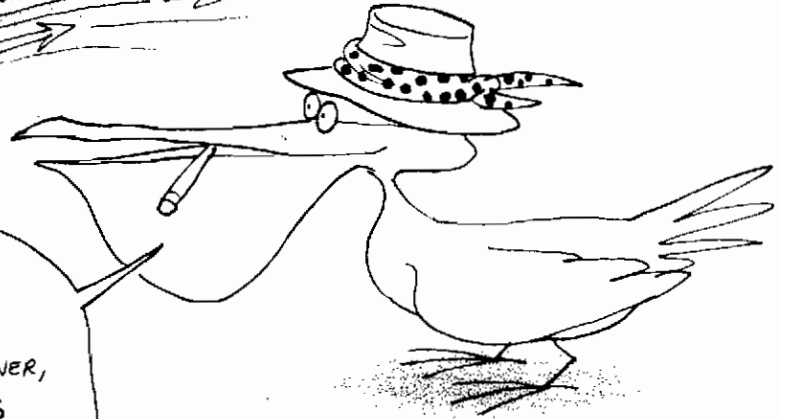
OK, NOW THAT WE'VE SORTED ALL THAT OUT, I WANT TO STUDY THE FLOW OF A FLUID AROUND A CONTOUR. I'LL START IN A REGIME WHERE THE SPEED V OF THE FLUID IS LESS THAN V_s .

I'LL FAKE UP A BOAT SHAPE WITH THREE SUCCESSIVE CORNERS.

THE FLUID ACCELERATES AT THE BOW, WHICH FORMS A CONVERGENT REGION.



HMMM... YUR, THAT'S WOT IT BOILS DAHN TER. THE SPEED'S FASTEST ARAHND THE SECOND CORNER, THE BEAM. SO THE FLUID SLOWS DAHN UNTIL IT REACHES THE STERN, STAYIN' AT A CONSTANT BLINKIN' LEVEL UNTIL IT GETS BACK TER THE SAME SPEED WOT IT 'AD AT THE BOW.



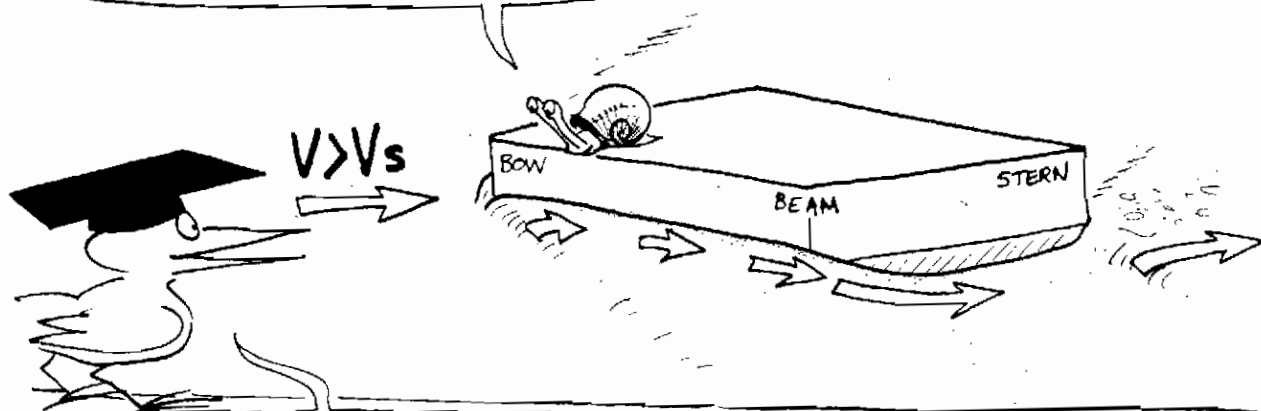


THE SURFACE WAVES, TRAVELING AT A SPEED V_s , CAN MOVE UPSTREAM AND TRANSMIT ENERGY TO THE FLUID. SO THE FLUID "KNOWS" THAT AN OBJECT IS COMING AND HAS TIME TO GET ITSELF READY TO MEET IT. IT BEGINS TO MOVE APART BEFORE THE OBJECT ARRIVES.

ACHOO UPSTREAM!
HERE WE COME!

NOW I'M GOING TO TILT THE CHANNEL A BIT MORE SO THAT THE SPEED V OF THE FLUID BECOMES GREATER THAN THE SPEED V_s OF SURFACE WAVES.

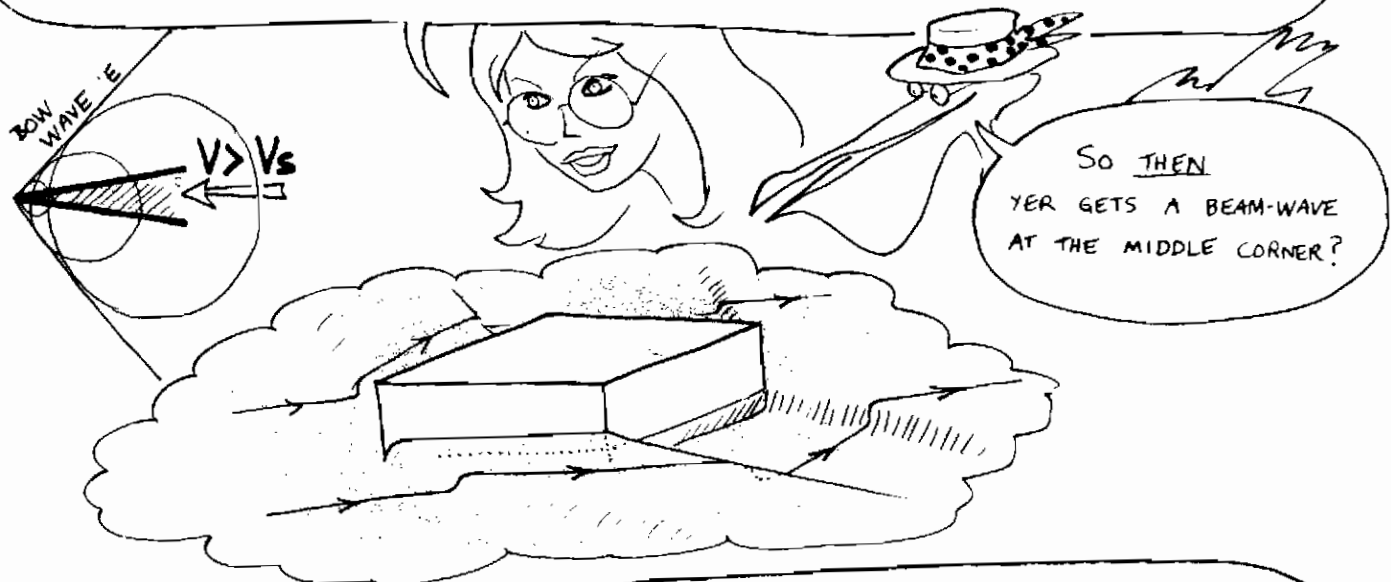
BY HUGONOT'S THEOREM, WE KNOW THAT THE FLUID SLOWS DOWN AT THE BOW, SPEEDS UP AT THE BEAM, AND SLOWS DOWN AGAIN AT THE STERN.



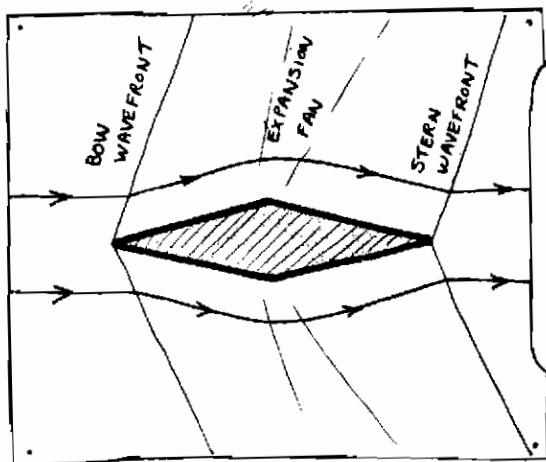
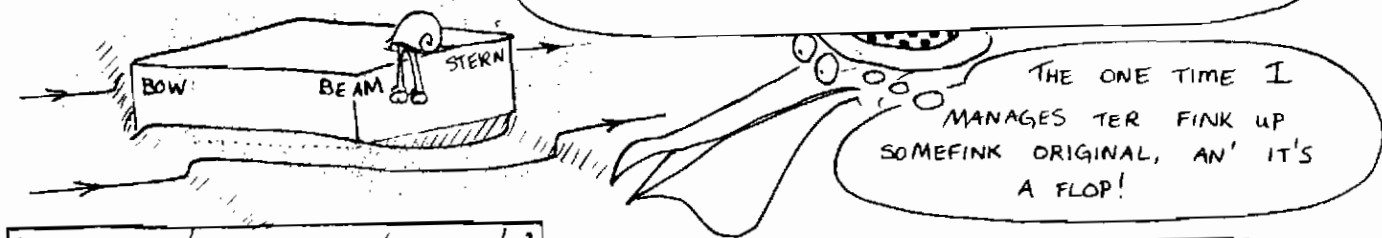
LEVEL WITH THE BOW, THE WATER IS SUDDENLY SLOWED DOWN AND RISES HIGHER THAN THE ORIGINAL WATERLINE. ON PASSING THE SECOND CORNER, THE WATER IS SPEEDED UP AGAIN, EVEN SUPERACCELERATED, THAT IS, INCREASED TO A SPEED GREATER THAN THAT OF "FREE" FLOW. AT THE SAME TIME THE LEVEL DROPS BELOW THE WATERLINE. LEVEL WITH THE STERN, THE SPEED AND LEVEL ARE SUDDENLY READJUSTED TO THEIR ORIGINAL VALUES UPSTREAM.

THE BOW WAVE

IN THIS REGIME, WHERE THE SPEED V IS GREATER THAN THE SPEED V_s OF SURFACE WAVES, WE FIND **WAVEFRONTS**. THE BOW, FOR EXAMPLE, EMITS SURFACE WAVES THAT TRAVEL TOO SLOWLY TO MOVE UPSTREAM AND THEREFORE PILE UP AGAINST EACH OTHER TO FORM A MOUND OF LIQUID, THE **BOW WAVE**.

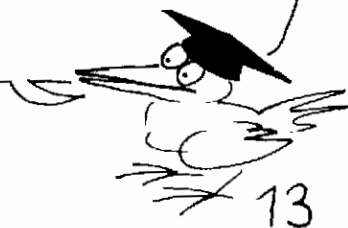


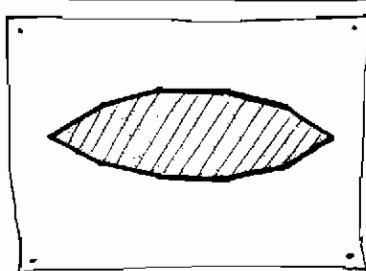
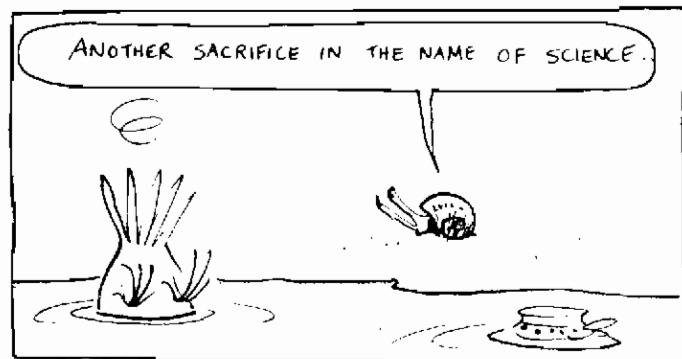
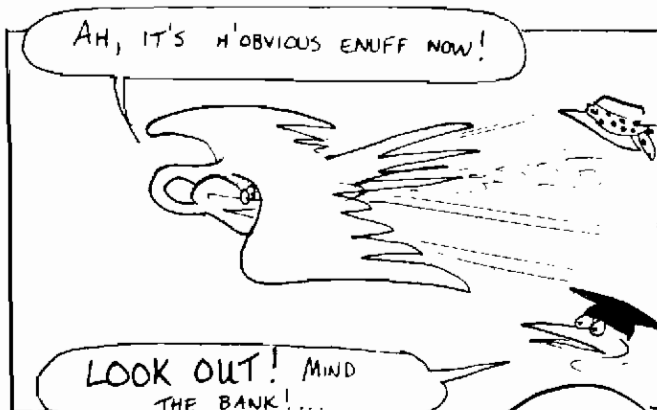
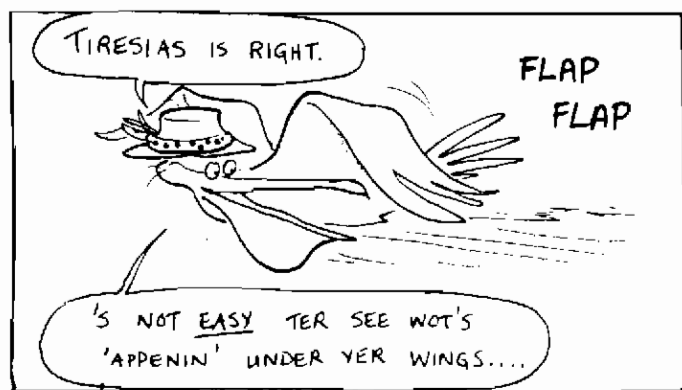
NO, YOU DON'T GET "EXPANSION FRONTS." LOOKS AS IF THEY ONLY HAPPEN GENTLY.



TIRESIAS IS RIGHT, LENNY. THE CHANGES IN SPEED AND LEVEL HAPPEN SUDDENLY AT THE BOW AND STERN, BY MEANS OF **WAVEFRONTS**. IN CONTRAST, AT THE BEAM, THE SPEED AND LEVEL CHANGE CONTINUOUSLY, ACROSS AN **EXPANSION FAN**.

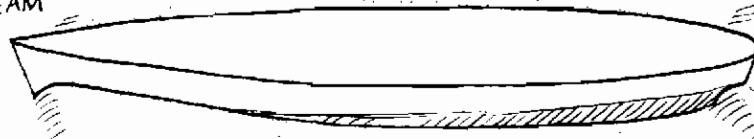
OBSERVATION, LENNY. OBSERVATION!





IN A REAL BOAT HULL, THE BEAM IS FORMED BY A SUCCESSION OF VERY MANY TINY CORNERS.

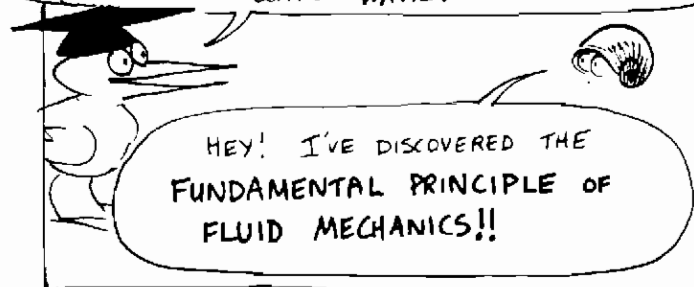
UPSTREAM



DOWNSTREAM

AND THE STERN WAVE ASSURES A SMOOTH JOIN WITH THE FLUID DOWNSTREAM— WHICH IS WHY BOATS DON'T LEAVE FURROWS BEHIND THEM.

IN THE SAME WAY, THE REMAINING DIFFERENCE IN SPEED, DUE TO WATER BEING CARRIED ALONG WITH THE BOAT BY FRICTION, IS CANCELLED OUT BY THE TURBULENCE OF THE BOAT'S WAKE.



YET AGAIN, TIRESIAS OLD BEAN, YER ASTOUNDS ME. WHAT?



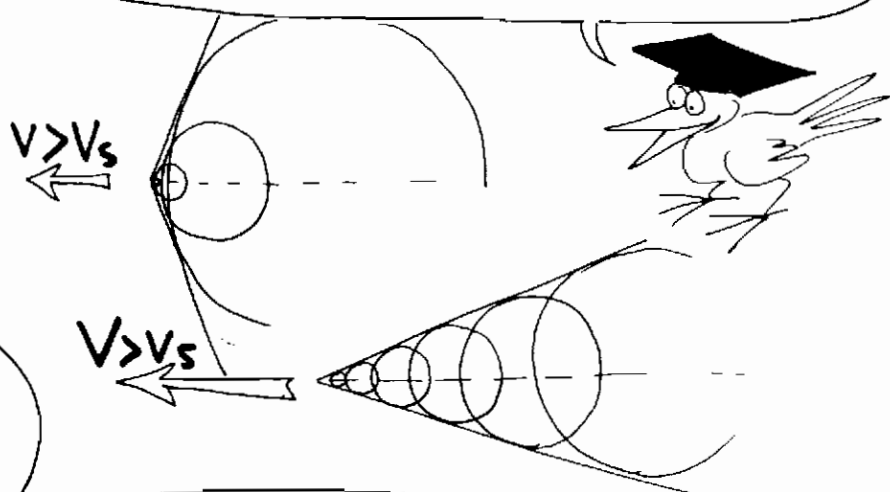
PLEASE LEAVE THE FLUID IN THE STATE IN WHICH YOU WOULD WISH TO FIND IT

MEASUREMENT OF SPEED

TO UNDERSTAND WHAT'S GOING ON, WHAT I NEED IS SOME WAY TO MEASURE SPEED.

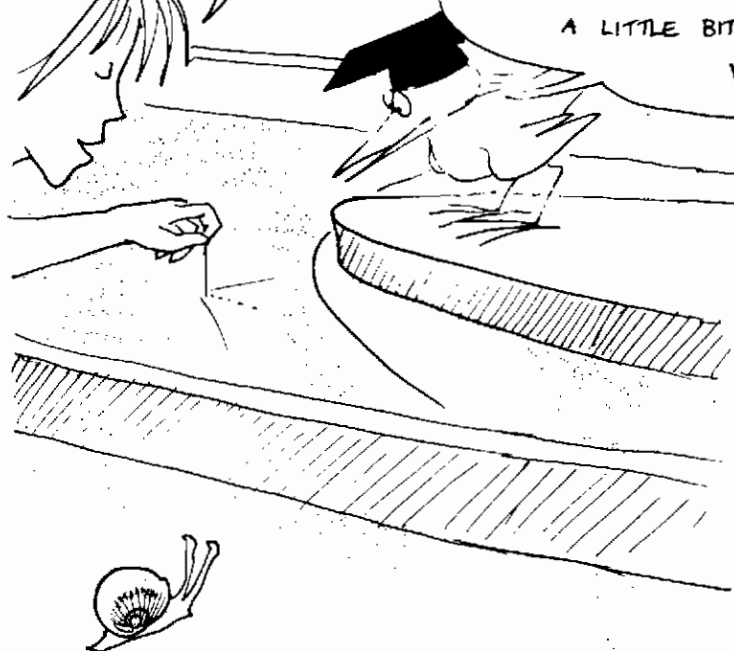


IF YOU PLACE A FINE NEEDLE IN A FLOW WHOSE SPEED V IS GREATER THAN THE SPEED V_s OF SURFACE WAVES, THEN THE GREATER THE SPEED, THE CLOSER THE WAVEFRONTS ARE TO THE DIRECTION OF MOTION.



WOW, MAX, YOU'RE RIGHT! THAT LETS ME MEASURE THE SPEED V .(*)

HAVE YOU NOTICED THAT WHEN THE FRONT OF THE OBJECT IS BLUNT, THEN THE WAVEFRONT IS SET UP A LITTLE BIT AHEAD - FORMING A DETACHED WAVE.

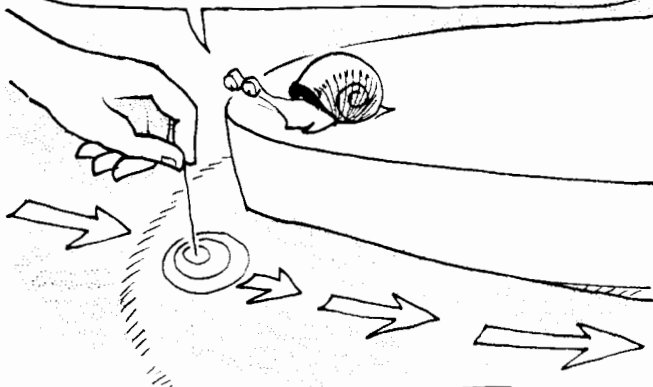


(*) SEE APPENDIX A (PAGE 71).

THAT'S ONLY TO BE EXPECTED. IN THIS REGION, NEAR A BLUNT BOW, THE SPEED V FALLS BELOW THE CRITICAL SPEED V_s .

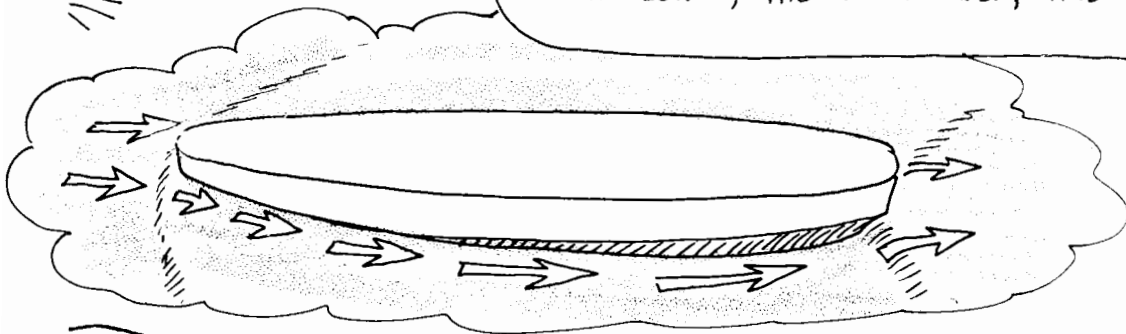


IT'S ALMOST AS IF THE OBJECT USES THE BOW WAVE TO BUILD ITSELF A REGION WHERE V IS LESS THAN V_s TO MAKE IT EASIER TO NAVIGATE.



BUT THEN, 'OW CAN THE WATER GEDDAHT O' THE WAY, WHEN ITS SPEED'S SO BLINKIN' LOW?

ELEMENTARY, MY DEAR PELICAN: WHERE THE FLUID SLOWS DOWN, THE LEVEL RISES, AND VICE VERSA.



COME ALONG, YE SEEKERS AFTER KNOWLEDGE! DINNER TIME!

IT'S ALL BEGINNING TO MAKE SOME KIND OF SENSE.



YOU KNOW, IT WOULDN'T BE A BAD THING IF YOU COULD GET RID OF THOSE WAVES.

THEY WASTE ENERGY, THAT'S FOR SURE!

OH 'ECK!
SUMFINK'S
BREWIN'!

YES, THERE'S ENERGY THERE ALL RIGHT. THE PROOF IS THAT THE GUY IN THE SPEEDBOAT DEMOLISHED OUR LANDING-STAGE.

IF YOU COULD GET ADVANCE WARNING OF THE FLUID AHEAD, THE WAVE WOULDN'T FORM....

SO... TO MOVE FASTER THAN SURFACE WAVES, YOU HAVE TO BE ABLE TO CONTINUE TO ACT ON THE FLUID UPSTREAM.

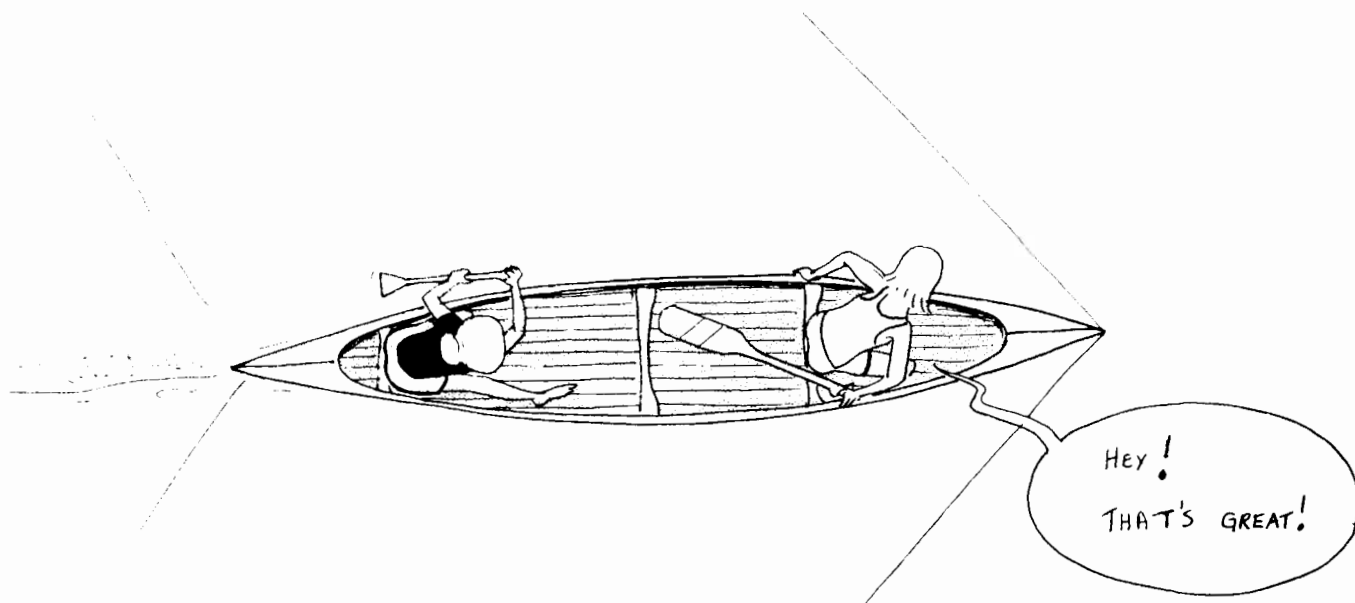
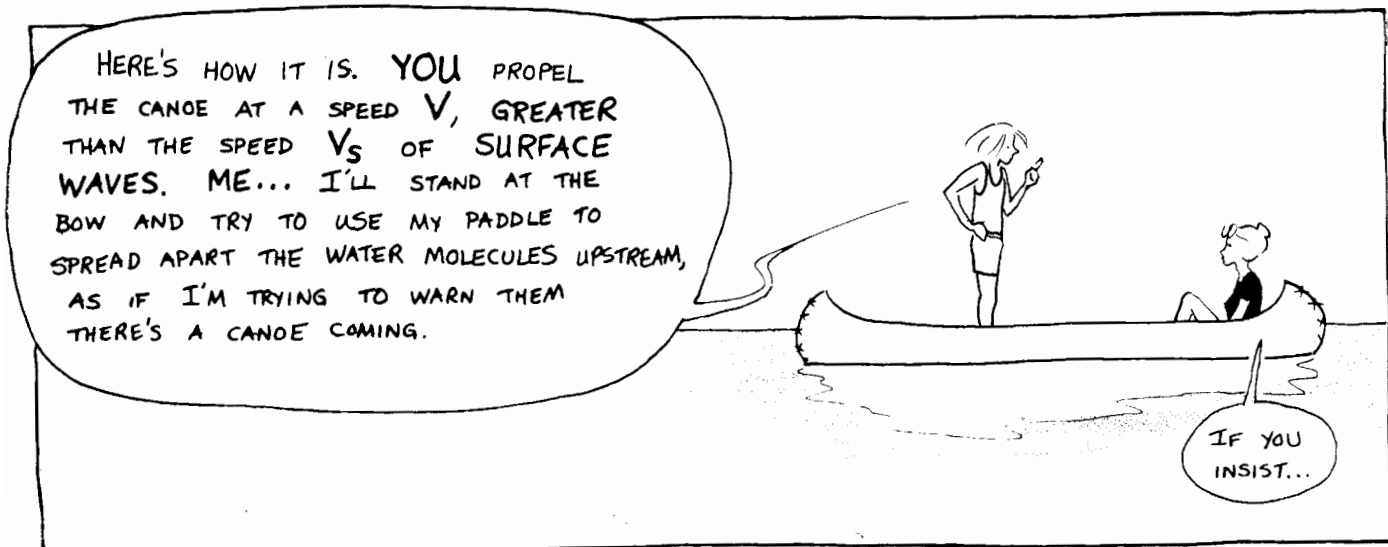
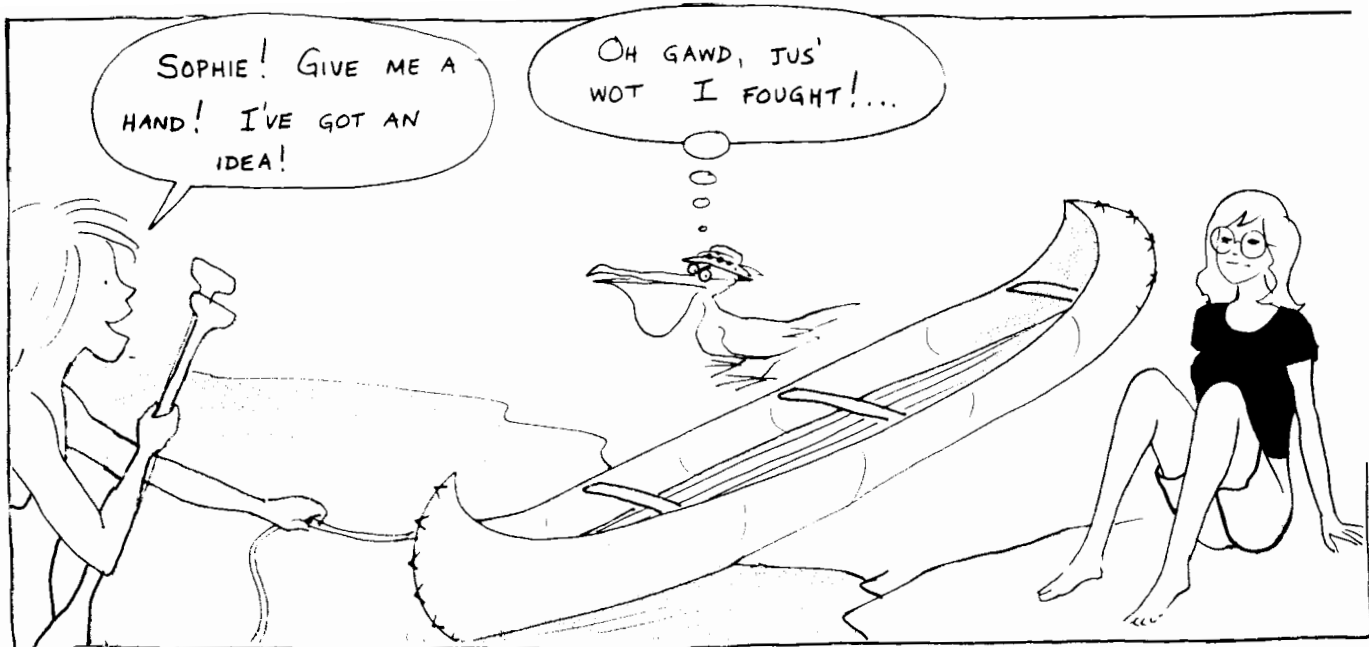
HEY!

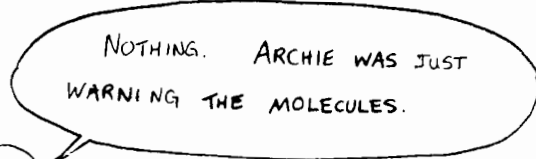
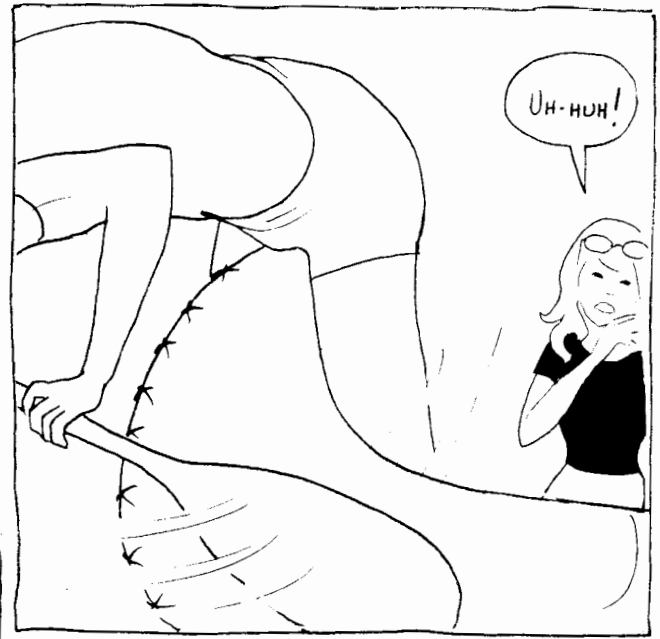
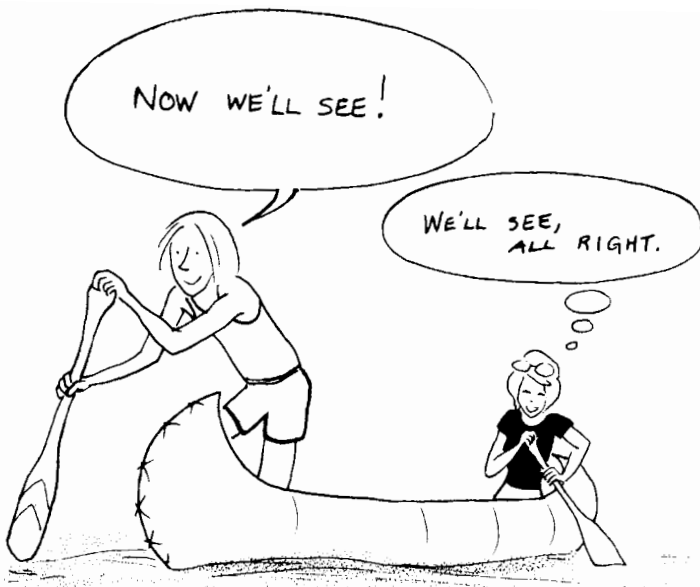
DISHES,
ARCHIBALD....

THERE'S GOT TO
BE A WAY.

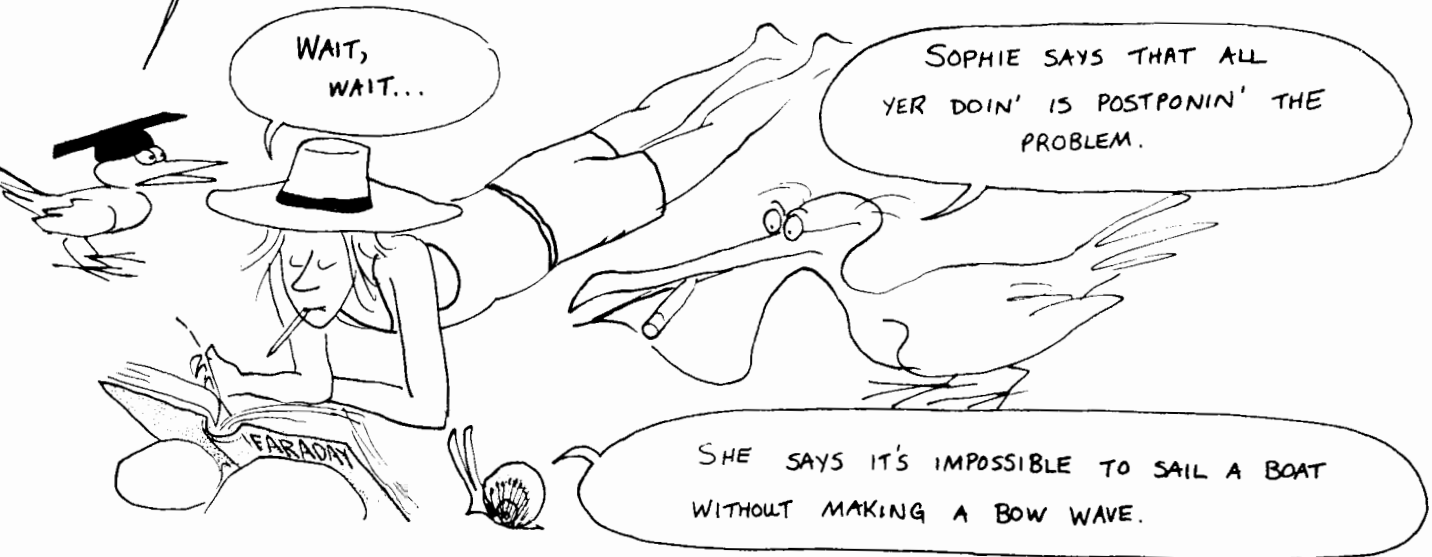
AHA!

SNAP!



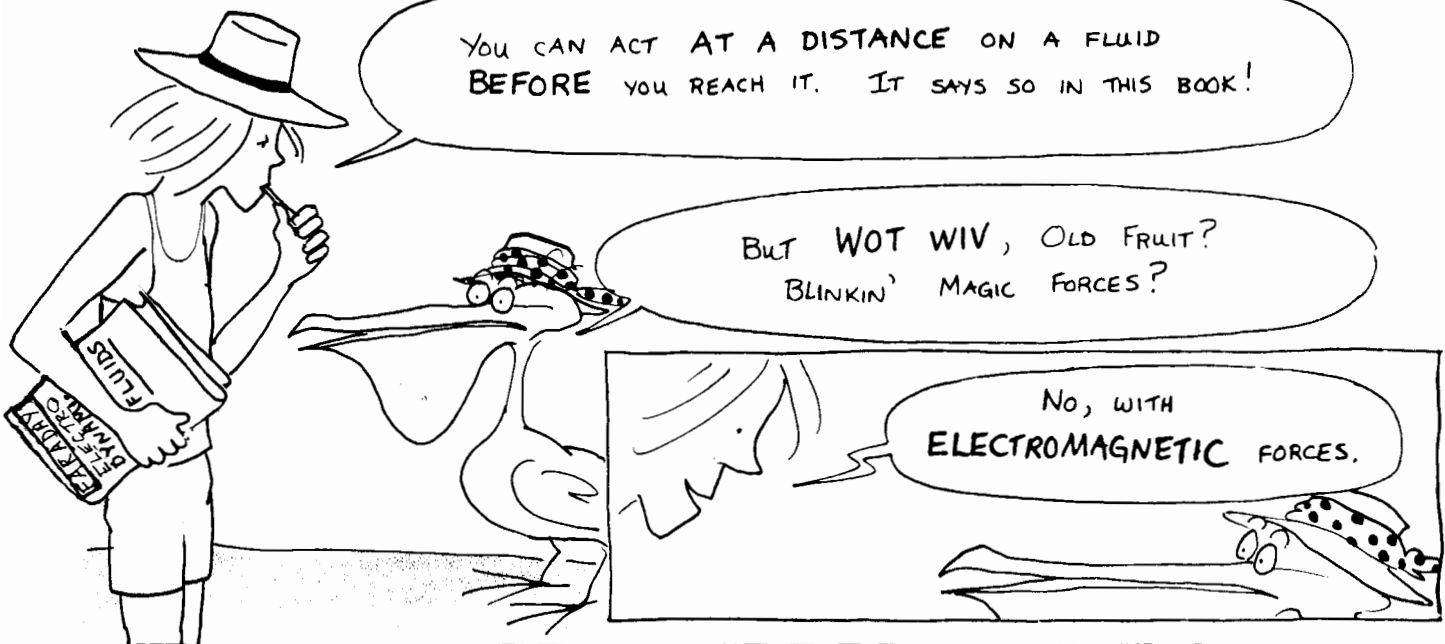


IT CAN'T POSSIBLY WORK, YOU KNOW! IF YOU WANT TO "WARN" THE MOLECULES, AS YOU SAID, THEN YOU'VE GOT TO PUT SOME OTHER MATERIAL OBJECTS INTO THE WATER UPSTREAM... AND THOSE WILL JUST CREATE THEIR OWN WAVES. IT'S A VICIOUS CIRCLE.



SHE SAYS IT'S IMPOSSIBLE TO SAIL A BOAT WITHOUT MAKING A BOW WAVE.

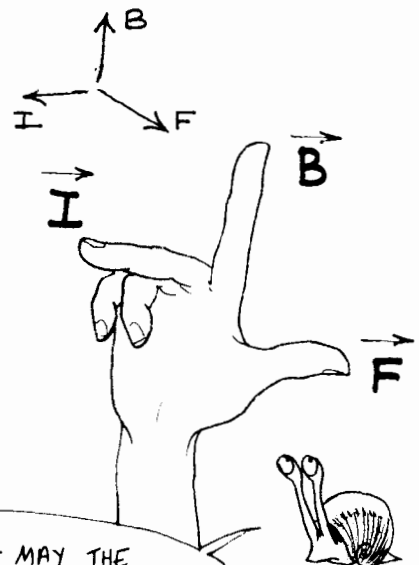
IN WHICH ARCHIE DISCOVERS MAGNETOHYDRODYNAMICS



IF, IN A FLUID, YOU CREATE A MAGNETIC FIELD \vec{B} AND AN ELECTRIC CURRENT \vec{I} , WHICH IS PERPENDICULAR, THEN THE FLUID EXPERIENCES A LAPLACE FORCE OF INTENSITY IB , WHOSE DIRECTION IS GIVEN BY THE

RIGHT-HAND RULE:

HOLD THE THUMB, INDEX FINGER, AND MIDDLE FINGER OF THE RIGHT HAND AS SHOWN. SUPPOSE THAT THE CURRENT FLOWS IN THE DIRECTION OF THE MIDDLE FINGER AND THE MAGNETIC FIELD, IN THE DIRECTION OF THE INDEX FINGER. THEN THE FORCE ACTS IN THE DIRECTION OF THE THUMB.



The Boss

FLIPPIN' ECK - WOT'S
THIS FINGAMAJIG?

I'VE MADE A
MAGNETO HYDRODYNAMIC
CONVERTER LIKE THE ONE
INVENTED IN 1860 BY THE
ENGLISH PHYSICIST FARADAY.

CONVERTER?
WHY?

BECAUSE IT CONVERTS ELECTRICAL ENERGY INTO
MOTION - OR KINETIC ENERGY.

THE MAGNETIC FIELD VECTOR \vec{B} AND THE
CURRENT VECTOR \vec{I} , TOGETHER WITH THE AXIS
OF THE CANAL, FORM AN ORTHOGONAL
COORDINATE FRAME.

THE COIL PRODUCES A MAGNETIC FIELD, AND I'VE ADDED SALT TO THE WATER TO INCREASE
ITS ELECTRICAL CONDUCTIVITY. I CAN USE THIS RHEOSTAT TO ALTER THE AMOUNT OF
CURRENT FLOWING THROUGH THE WATER.

BY VARYING THE CURRENT
 \vec{I} AND THE MAGNETIC
FIELD \vec{B} YOU CAN MAKE
THE FLUID ACCELERATE
OR DECELERATE AT WILL.

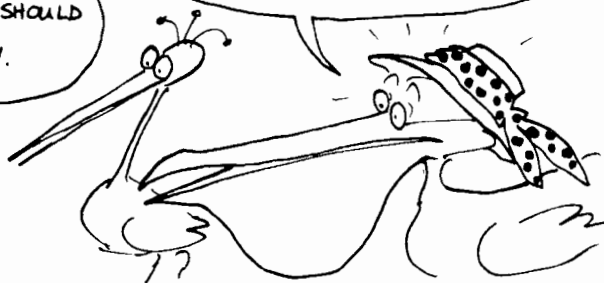
INTERACTION CRITERION



... BUT LET'S NOT WORRY ABOUT THAT NOW. LOGICALLY, IF THE ENERGY TRANSMITTED BY THE LAPLACE FORCES IS GREATER THAN THE KINETIC ENERGY OF THE FLUID, WE SHOULD BE ABLE TO CONTROL THE FLOW COMPLETELY.



WHAAT!?!
MAX, YER GORN
BONKERS!!!

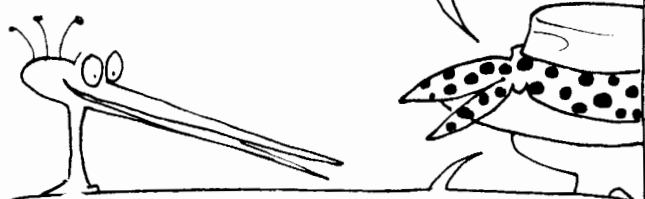


WELL, I MUST SAY, WE REALLY ARE
ALL HAVING FUN AND GAMES TODAY.
AREN'T WE?



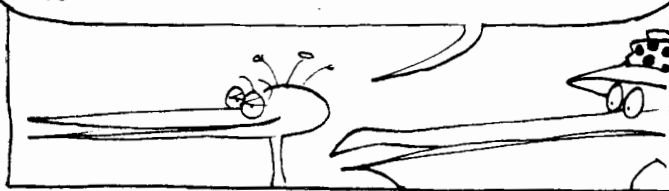
SAY NO MORE, SUNSHINE, SAY NO MORE.
YER KNOWS NOT BLINKIN' 'IGGINS IS LIKE.
GIVE 'IM AN INCH AN' 'E'LL 'ANG 'IMSELF!

IF ONLY SOPHIE WERE 'ERE! BUT SHE'S
SUNNIN' 'ERSELF ON THE BEACH.

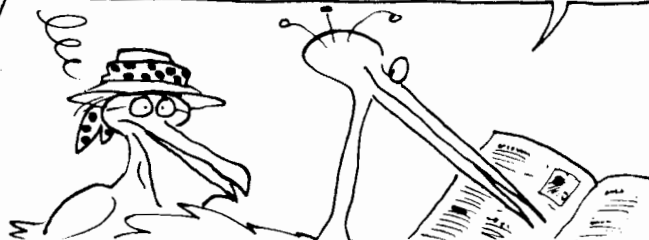


BLEEDIN' NONSENSE ANYWAY, 'IS RUDDY
MOSQUITO - 'YDRO-DYNAMO - WOTSIT....

BAH, YOU'RE AFRAID OF YOUR OWN
SHADOW! IT'S ALL LOW-VOLTAGE STUFF
ANYWAY. THE SKY WON'T FALL IN WITH
40 VOLTS AND 10,000 GAUSS, DAMMIT!



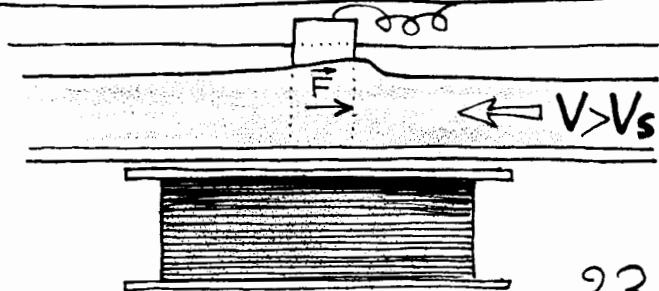
COME ON NOW... MAGNETOHYDRODYNAMICS,
ABBREVIATED MHD... YOU'LL EVEN FIND IT
IN THE DICTIONARY!



Wow! Look!



BY USING THE SYSTEM AS A DECELERATOR AND USING JUST
THE RIGHT AMOUNT OF ENERGY, I'VE MANAGED TO CREATE A
STATIONARY WAVE FRONT WITH NO OBSTACLE OTHER THAN THE
LAPLACE FORCES IB.





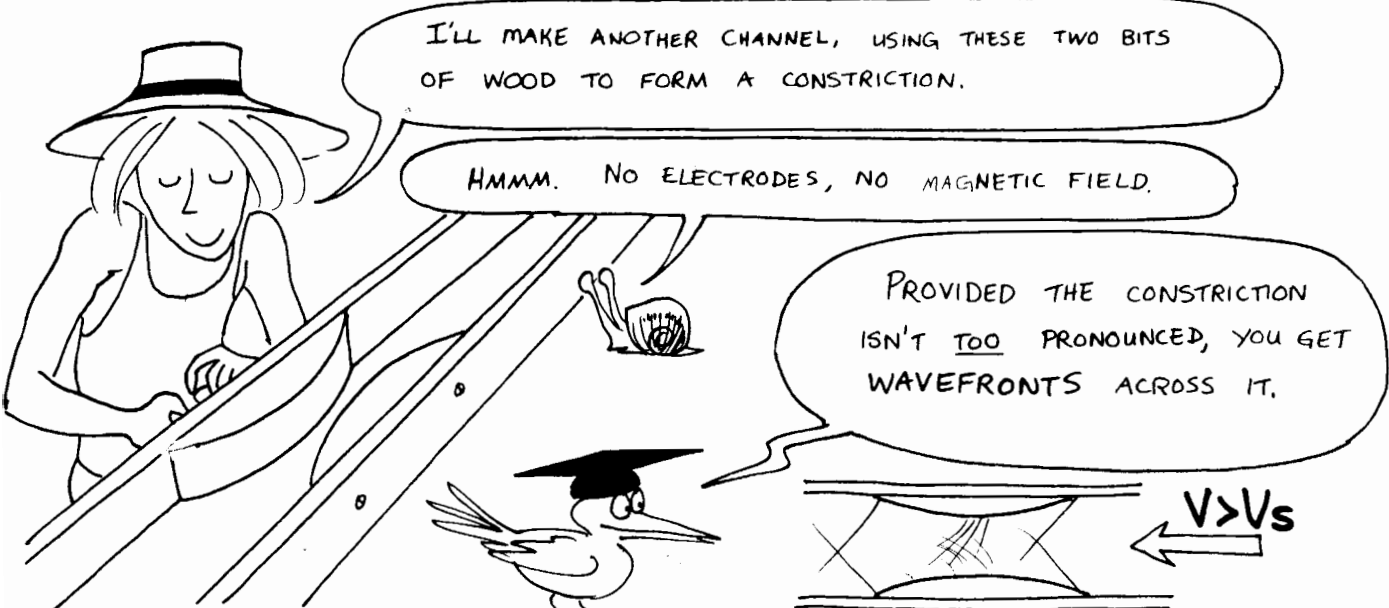
MY WORD,
HE HAS TOO!

YUR, GREAT. NOW NOT?

BUT THAT'S
CLASSICAL. IT'S BEEN
KNOWN FOR YEARS!

BLOCKAGE

IT'S ABSOLUTELY STANDARD,
TOTALLY CLASSICAL PHYSICS.

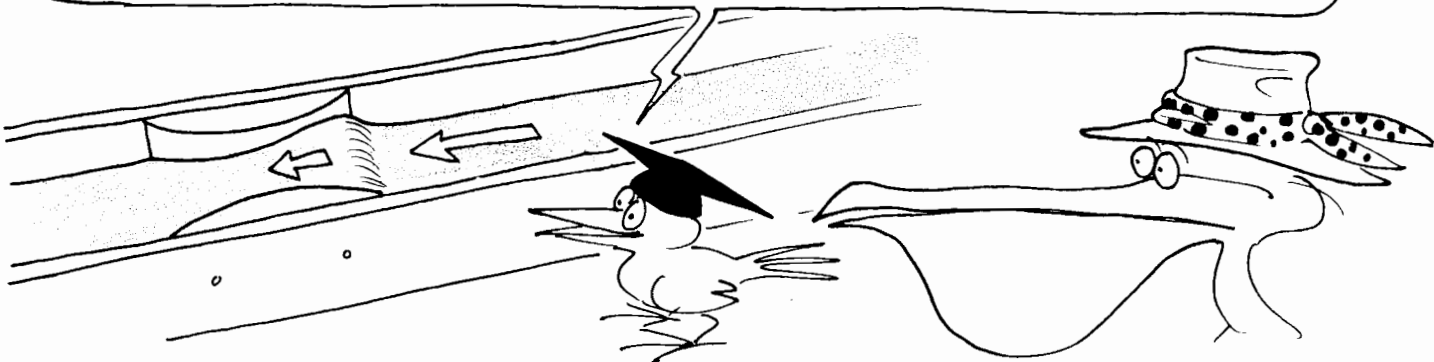


I'LL MAKE ANOTHER CHANNEL, USING THESE TWO BITS
OF WOOD TO FORM A CONSTRICTION.

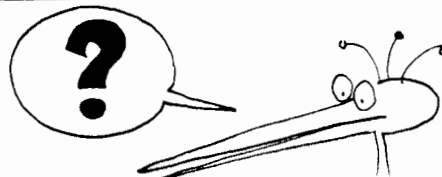
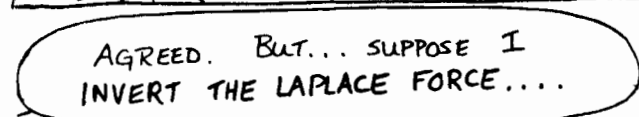
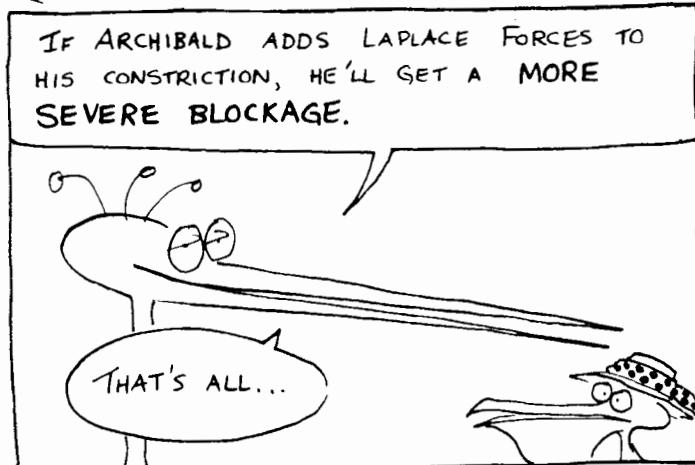
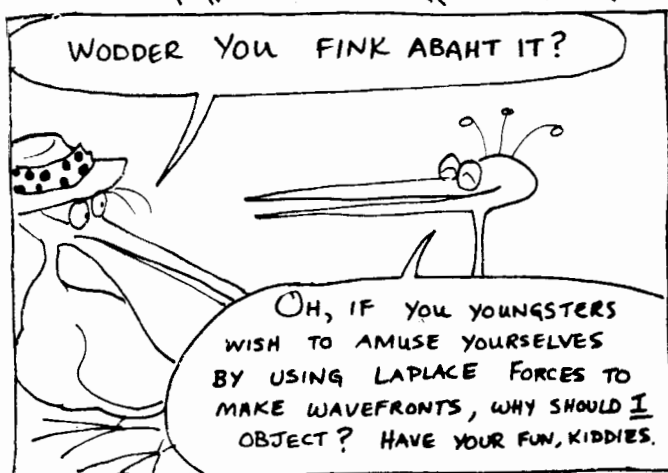
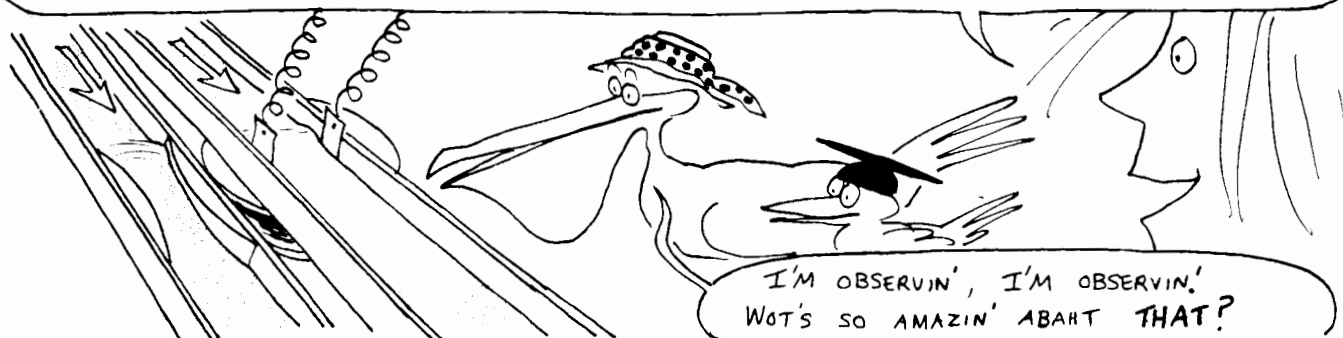
HMMM. NO ELECTRODES, NO MAGNETIC FIELD.

PROVIDED THE CONSTRICTION
ISN'T TOO PRONOUNCED, YOU GET
WAVEFRONTS ACROSS IT.

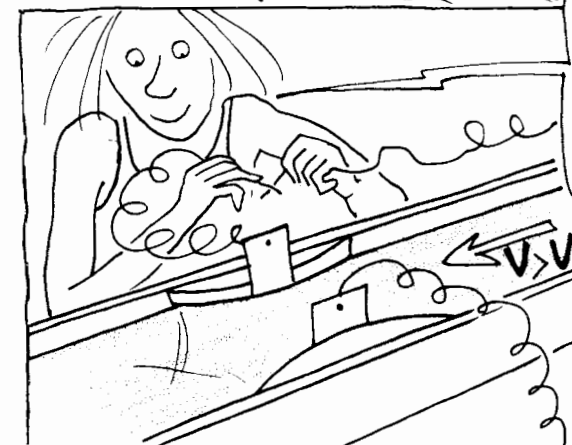
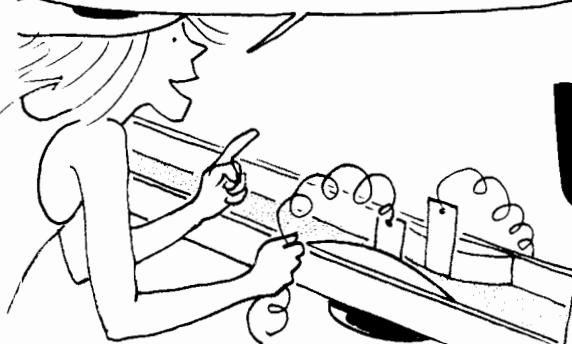
BUT IF THE CONSTRICTION IS SEVERE ENOUGH, THESE FRONTS MIGRATE
UPSTREAM, FORMING A FRONTAL WAVE THAT STABILIZES AT THE ENTRANCE
OF THE CONSTRICTION. EVEN THOUGH THE FLUID CAN STILL FLOW, WE CALL
THIS PHENOMENON A BLOCKAGE.



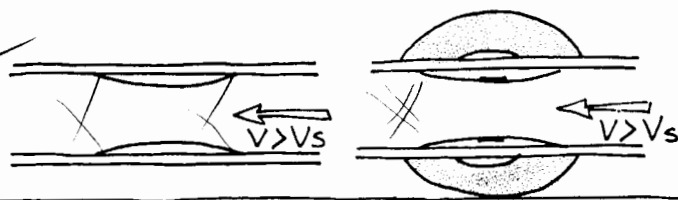
BUT NOW, OBSERVE HOW THE CUNNING EXPERIMENTER HAS USED A MAGNETIC FIELD TO REALIZE THE SAME BLOCKAGE AS THE ONE PRODUCED BY A CONSTRICTION.



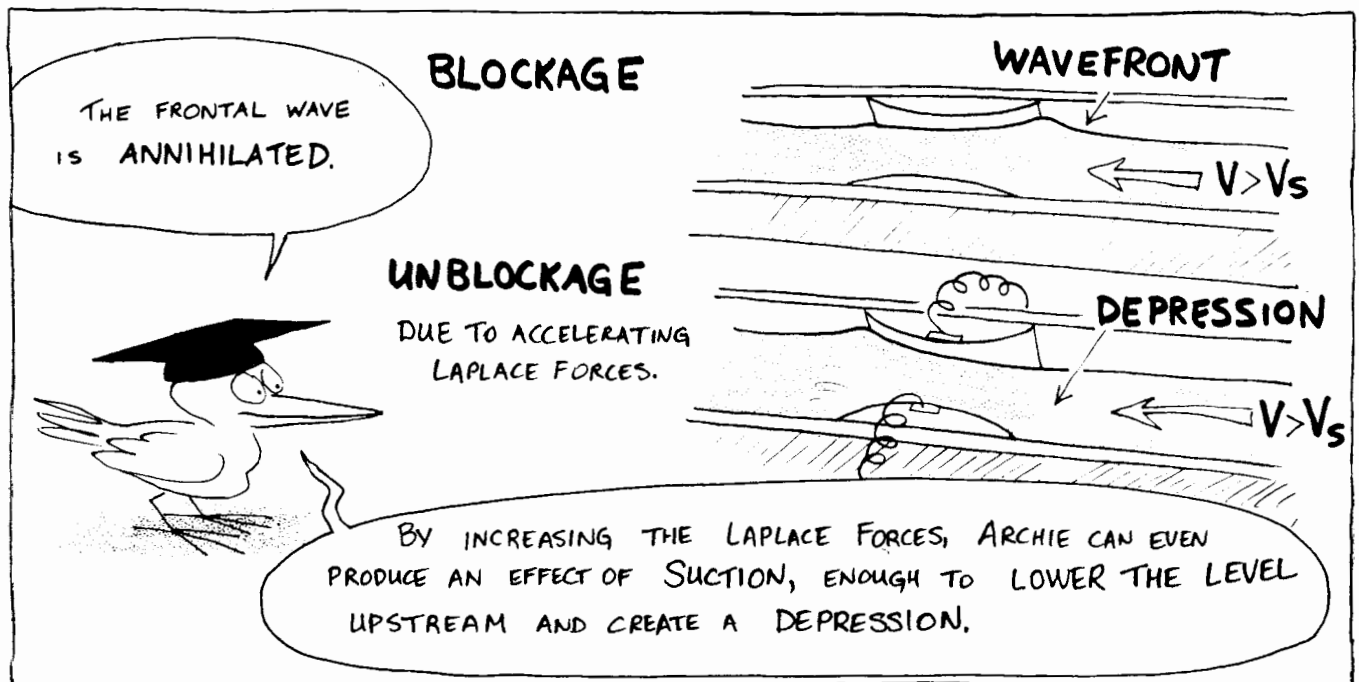
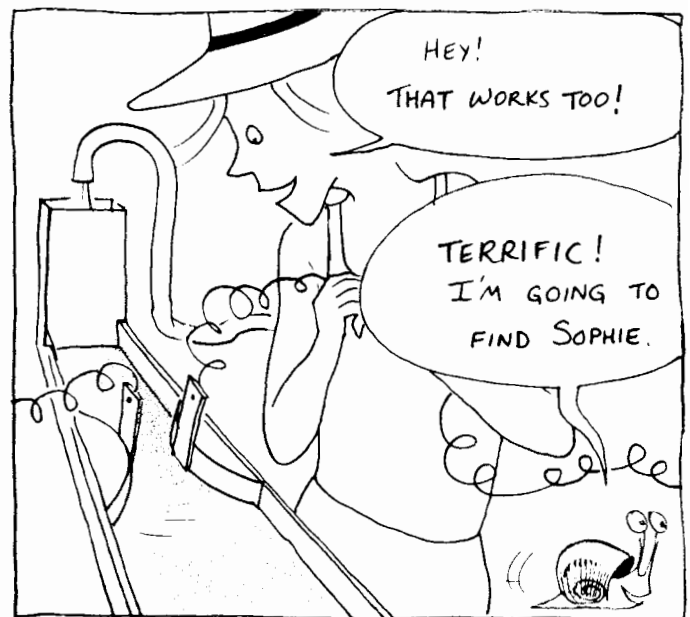
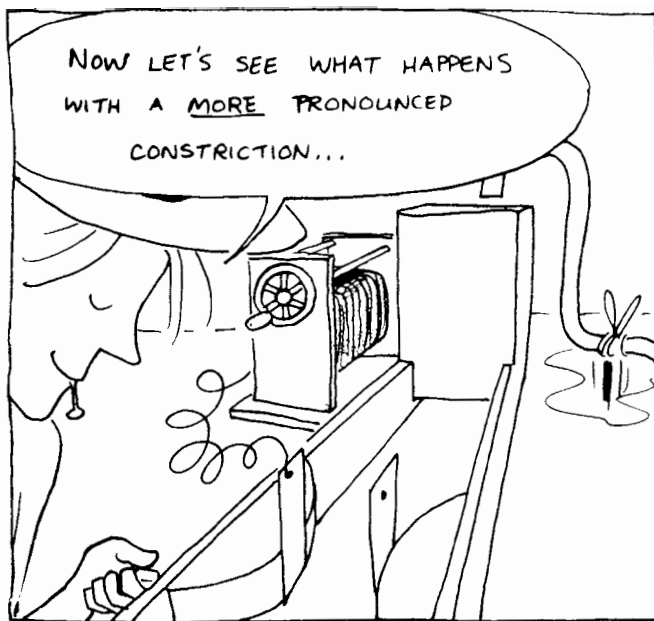
UNBLOCKAGE

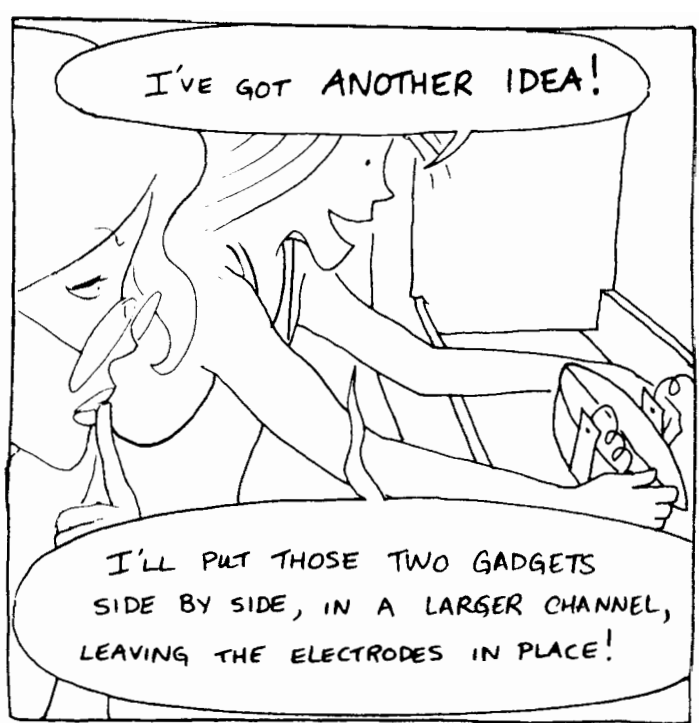


I'LL START WITH A LESS PRONOUNCED CONSTRICTION. TO INVERT THE FORCE, I CAN EITHER INVERT THE MAGNETIC FIELD \vec{B} OR INVERT THE CURRENT \vec{I} . HEY PRESTO! IF THE PRODUCT $\vec{I}\vec{B}$ IS LARGE ENOUGH (*) THEN THIS ACCELERATING LAPLACE FORCE MAKES THE WAVEFRONTS DISAPPEAR UPSTREAM!

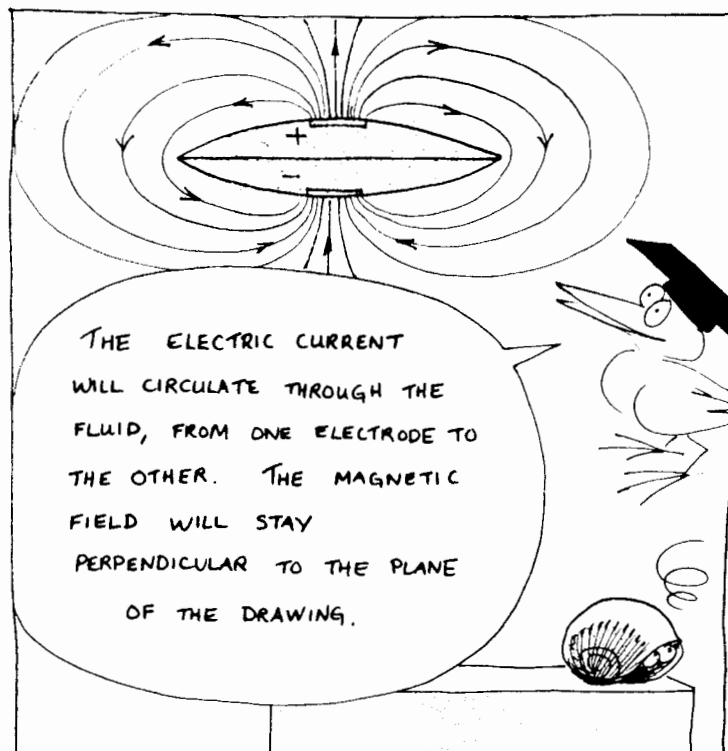


(*) SEE APPENDIX B (PAGE 71)

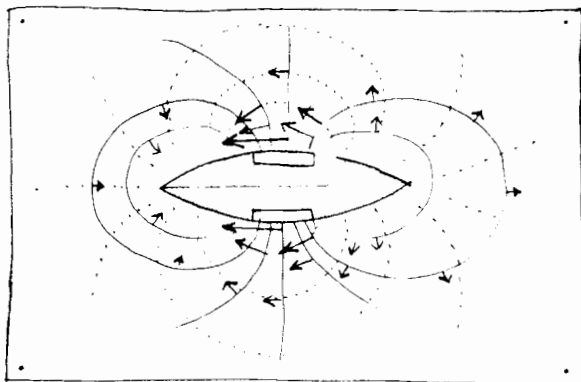




ANNIHILATION OF THE BOW WAVE

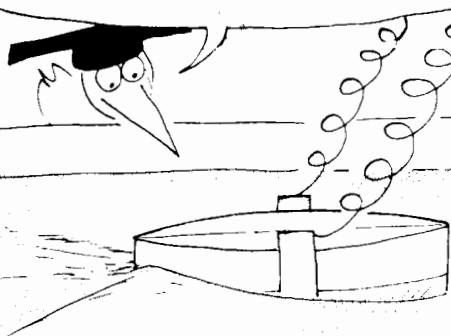


APPLYING THE
RIGHT-HAND RULE, I CAN
WORK OUT THE FIELD OF
FORCES THAT WILL ACT ON
THE FLUID.



SHIVER ME TIMBERS!

BY THE SHADES OF MAXWELL'S DEMON!
ARCHIE HAS ANNIHILATED THE
BOW WAVE!

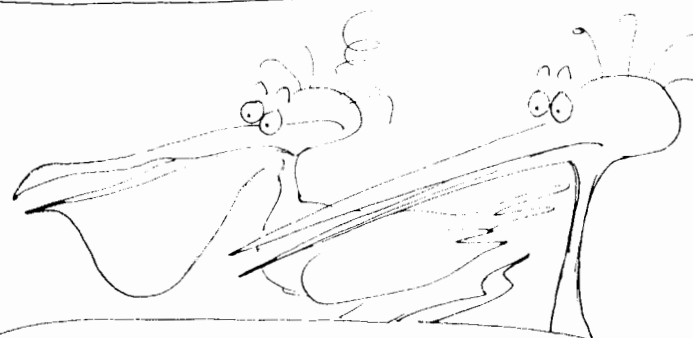
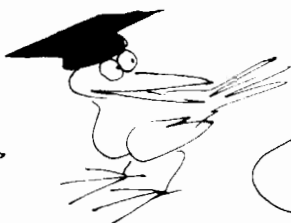


WHAT?

$V > V_s$

WHAT HAS HE
MANAGED TO COME
UP WITH?

NOTICE THAT ALTHOUGH HE'S SUPPRESSED THE BOW WAVE,
THE **STERN WAVE** STILL PERSISTS....



BUT — SURELY THAT'S KNOWN... ISN'T IT?

NO, IT CERTAINLY ISN'T KNOWN!
WHAT I'D LIKE TO KNOW IS, WHAT
DOES HE THINK HE'S PLAYING AT?

BUT YOU WERE SUPPOSED TO BE ENGAGED
IN SCIENTIFIC POPULARIZATION?

I DON'T UNDERSTAND....

WHEN YOU POPULARIZE THINGS
THAT AREN'T ALREADY KNOWN,
DO YOU REALIZE WHAT THAT'S
CALLED?

IT'S CALLED SCIENTIFIC RESEARCH.

THAT'S REELY TORN IT!

TOO
TRUE.

LET'S SEE... AHEAD OF A
MORE STUBBY OBJECT, THE FRONTAL
WAVE IS DETACHED.

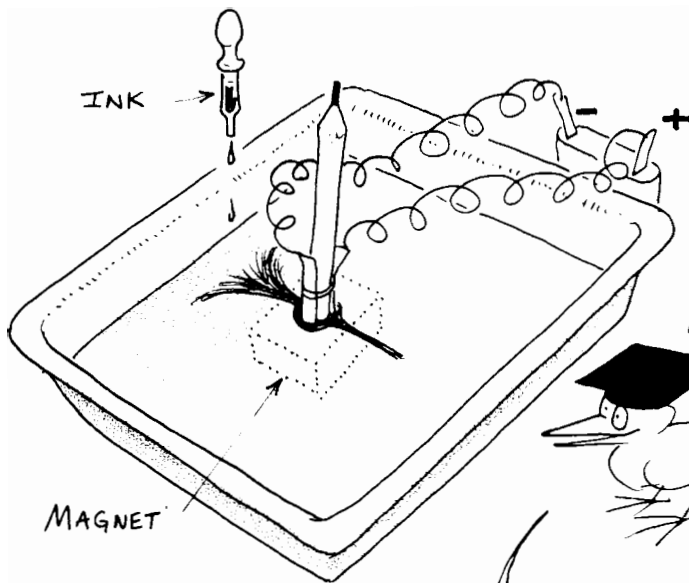
A DO-IT-YOURSELF MHD ACCELERATOR

AS A LIMITING CASE, THE
OBJECT COULD JUST BE A
CYLINDER.

ALL I NEED TO DO IS
FIX TWO COPPER ELECTRODES
ON A PENCIL. (*)

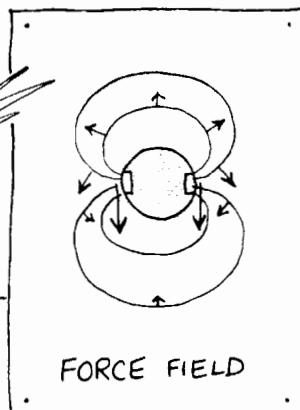
USING A BASIN OF SALTY WATER
AND A MAGNET, YOU CAN MAKE THE
PUMPING EFFECT OF LAPLACE FORCES
BECOME VISIBLE.

(*) AN ARRANGEMENT DEVISED IN 1976 BY MAURICE VITON.

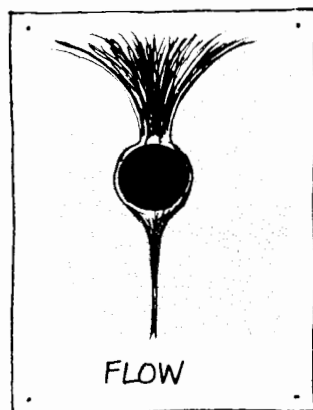


THE MAGNET, UNDERNEATH THE BASIN, PRODUCES A VERTICAL MAGNETIC FIELD \vec{B} . THE PUMPING EFFECT CAN BE SEEN BY USING A DROP OF INK.

MAGNET

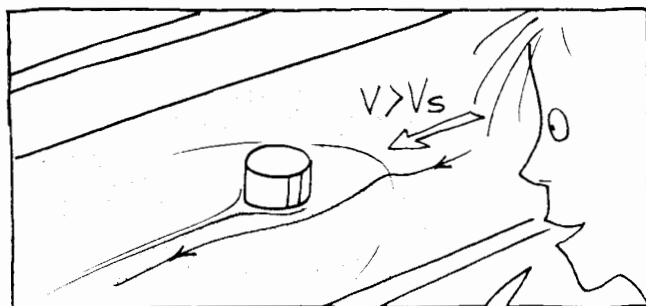


FORCE FIELD

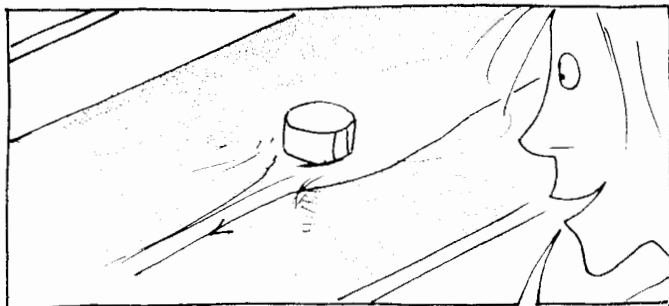


FLOW

WITH A SMALL PERMANENT MAGNET AND A BATTERY, YOU CAN OBSERVE THE PUMPING EFFECT. BUT TO ACT ON THE FLUID STRONGLY ENOUGH TO CHANGE THE STRUCTURE OF THE WAVEFRONTS, THE LAPLACE FORCES MUST BE TEN TIMES LARGER.



I'LL PLACE THIS MODEL IN THE TEST CHANNEL AND INCREASE THE FORCE. TO BEGIN WITH THE WAVE IS NONTURBULENT, AND THE FRONTAL WAVE BENDS.



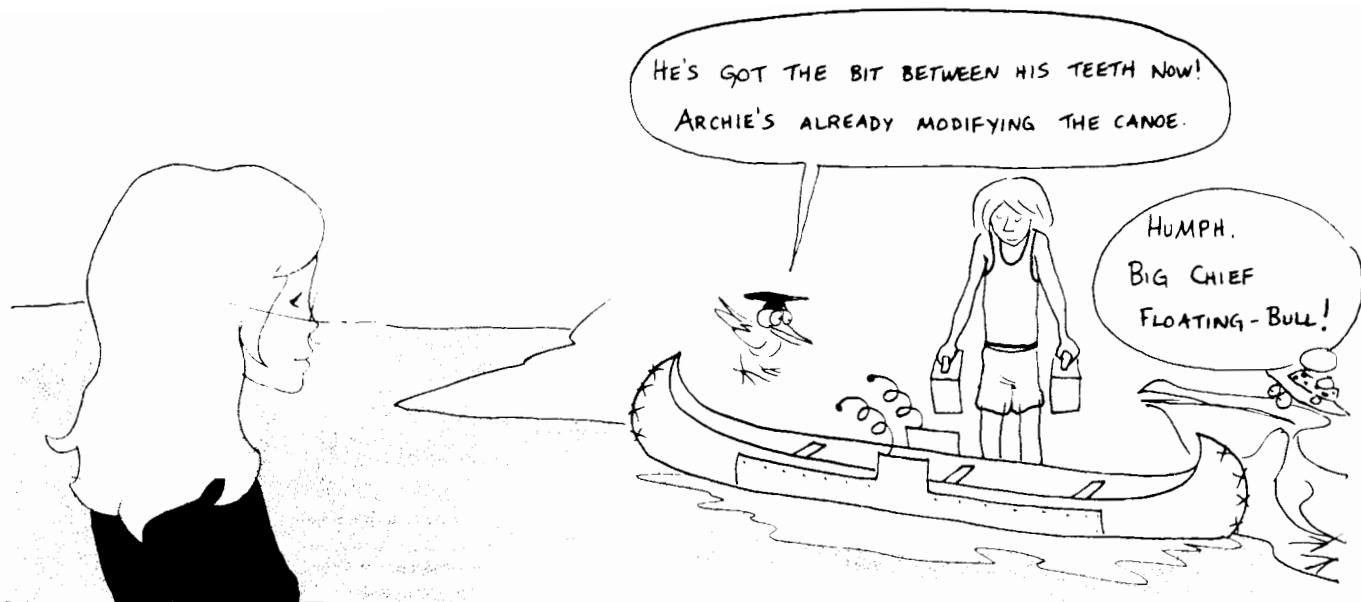
I'LL INCREASE THE FORCE FURTHER. THE FRONTAL WAVE DISAPPEARS, REPLACED BY A DEPRESSION IN THE LIQUID SURFACE.

GREAT! NOW FOR THE APPLICATIONS!

WAIT FOR ME, ARCHIE!

WODJER FINK, SOPHIE?

THE LAPLACE FORCES ACT AT A DISTANCE. I THINK ARCHIE HAS DISCOVERED HOW TO "WARN" THE FLUID UPSTREAM.



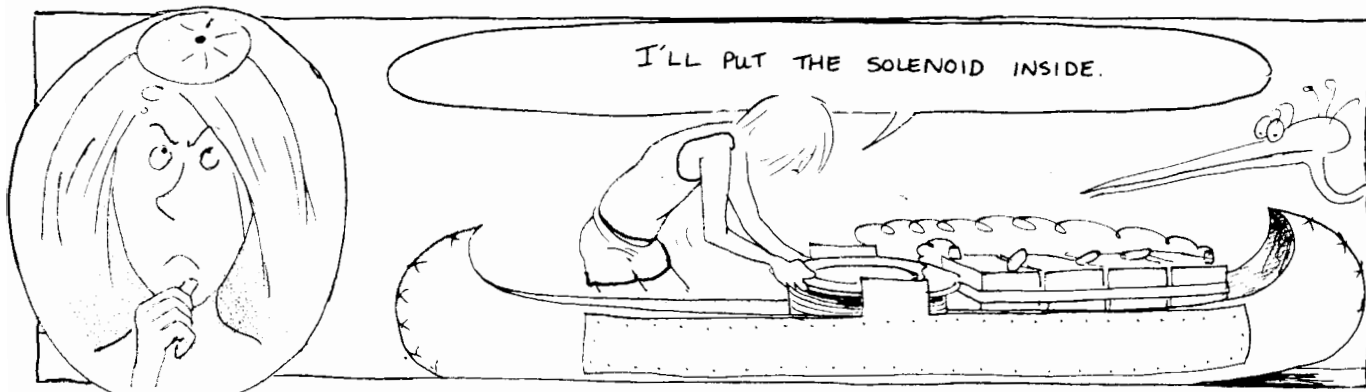
HE'S GOT THE BIT BETWEEN HIS TEETH NOW!
ARCHIE'S ALREADY MODIFYING THE CANOE.

HUMPH.
BIG CHIEF
FLOATING-BULL!

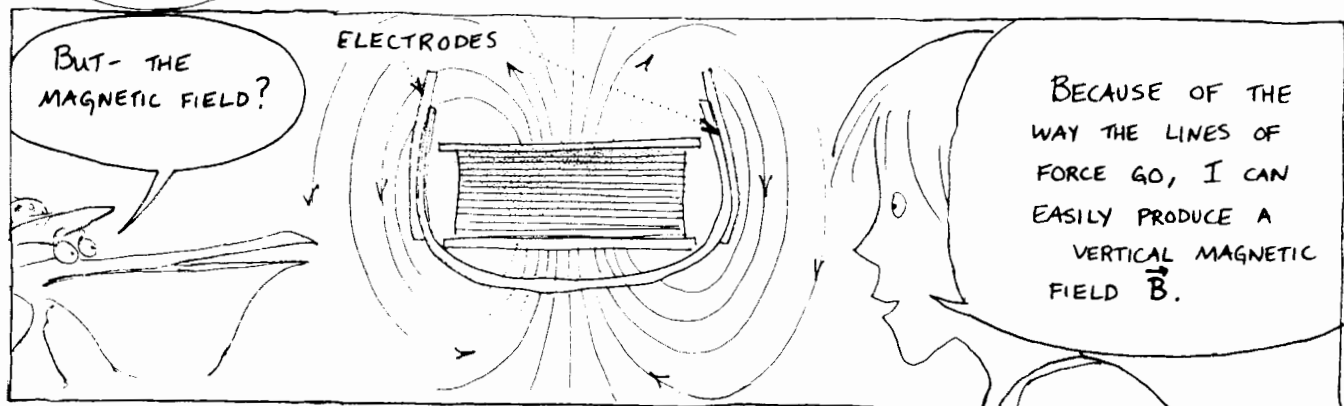


HOW WILL YOU ARRANGE
A MAGNETIC FIELD?

CRUIKEY! I FORGOT ALL ABOUT
THAT!



I'LL PUT THE SOLENOID INSIDE.

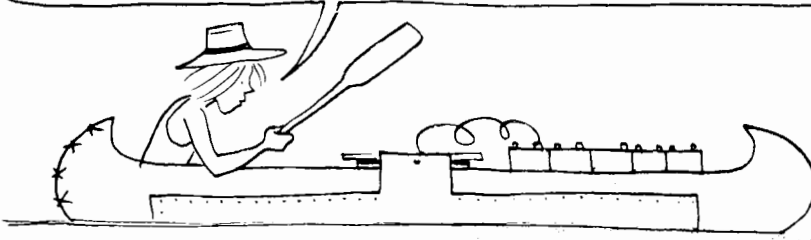


BUT- THE
MAGNETIC FIELD?

BECAUSE OF THE
WAY THE LINES OF
FORCE GO, I CAN
EASILY PRODUCE A
VERTICAL MAGNETIC
FIELD \vec{B} .

MHD PROPULSION

THE CUNNING EXPERIMENTER SETS OFF INTO THE UNKNOWN ABOARD HIS BOW WAVE ANNIHILATOR. ALL HE MUST DO NOW IS TO PADDLE THE CANOE AT A SPEED V GREATER THAN THE SPEED V_s OF SURFACE WAVES.



MY WORD! THE CANOE'S SAILING ALL BY ITSELF!

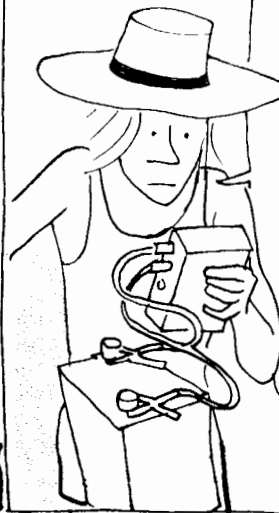
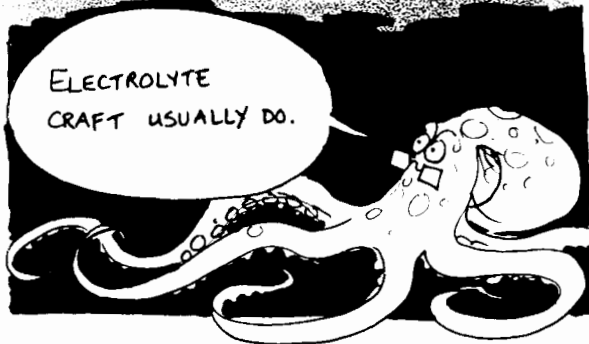


NORMAL ENOUGH. THE MHD SYSTEM PUMPS WATER TOWARD THE BACK, ALTERING THE BALANCE OF PRESSURE ON THE HULL. THE RESULT IS A PUSH.



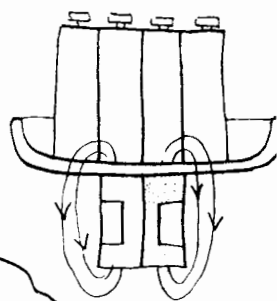
GEE! THAT BABY REALLY MOVES!

ELECTROLYTE CRAFT USUALLY DO.



DARN IT! THE CONFOUNDED BATTERY'S FLAT ALREADY. THAT SOLENOID USES AN AWFUL LOT OF ENERGY. I'LL TRY A SMALL MODEL WITH PERMANENT MAGNETS.

MHD EFFICIENCY



HOW ABOUT THIS FOR AN IDEA? THERE'S A PERMANENT MAGNET UNDER THE HULL, AND THE ELECTRODES ARE CONNECTED TO A BATTERY.



HECK, IT DOESN'T GO VERY FAST!
ONLY ONE GRAM OF PUSH...



WHEEEEEEEEE!

IT TAKES AS MUCH POWER AS A STEAM-IRON. (*)



CONTRARIWISE,
SUPPOSE I APPLY THE
SAME POWER TO A CONVENTIONAL
ELECTRIC MOTOR.



VARROOOOM

IT GOES LIKE THE WIND!

MAYDAY, MAYDAY!

WHAT HAPPENED?

YOUR MAGNETIC FIELD IS TOO
WEAK - THE METHOD OF PROPULSION
IS HIGHLY INEFFICIENT.

(*) SEE APPENDIX C (PAGE 71)

HUH? WHAT D'YOU MEAN?

THE BLADES OF THIS PROPELLER ARE INCLINED AT A DEFINITE ANGLE.

WHAT WOULD YOU THINK OF A PROPELLER THAT WAS INCLINED AT AN ANGLE OF A FRACTION OF A DEGREE?

IT WOULD BE INEFFICIENT. ONLY A TINY AMOUNT OF THE POWER WOULD BE USED FOR PROPULSION. MOST OF IT WOULD BE DISSIPATED IN THE FORM OF HEAT, THROUGH FRICTION.

AND THAT'S EXACTLY WHAT HAPPENS WITH YOUR MHD PROPULSION. SUPPOSE THE CURRENT I REPRESENTS THE NUMBER OF TURNS AND THE FIELD B THE ANGLE OF THE BLADES.

YOUR ANGLE IS TOO SMALL! ALL YOU'RE DOING IS HEATING THE WATER...

WITH PERMANENT MAGNETS, THE BEST YOU CAN HOPE FOR IS AN EFFICIENCY OF A FEW MILLIONTHS. (*) IN SEAWATER, BEFORE AN MHD MOTOR BEGINS TO BE INTERESTING, YOU NEED A MAGNETIC FIELD 250 TIMES GREATER: ABOUT 20 TO 25 TESLAS.

BUT WE KNOW HOW TO MAKE STRONG MAGNETIC FIELDS, DON'T WE?

SUPPOSE YOU COULD GET YOUR 25 TESLAS. THEN THE BOAT WOULD HAVE TO BE MUCH BIGGER AND SO WOULD THE DISTANCE BETWEEN THE ELECTRODES. IF IT WERE TEN METERS, THE GENERATOR WOULD HAVE TO PUT OUT 10,000 VOLTS.

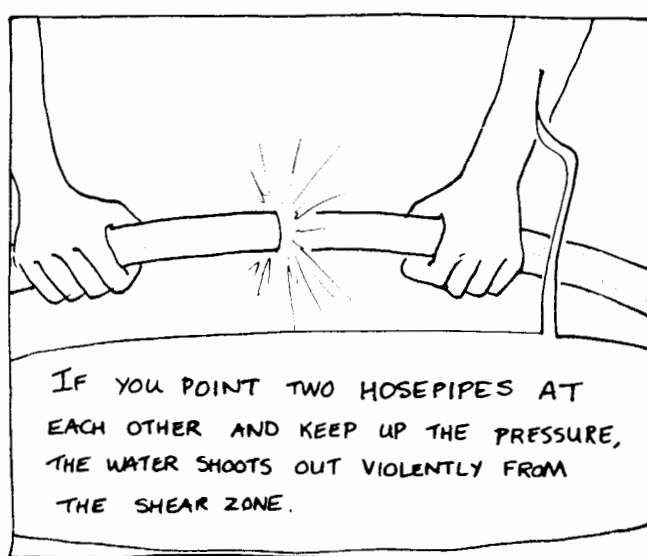
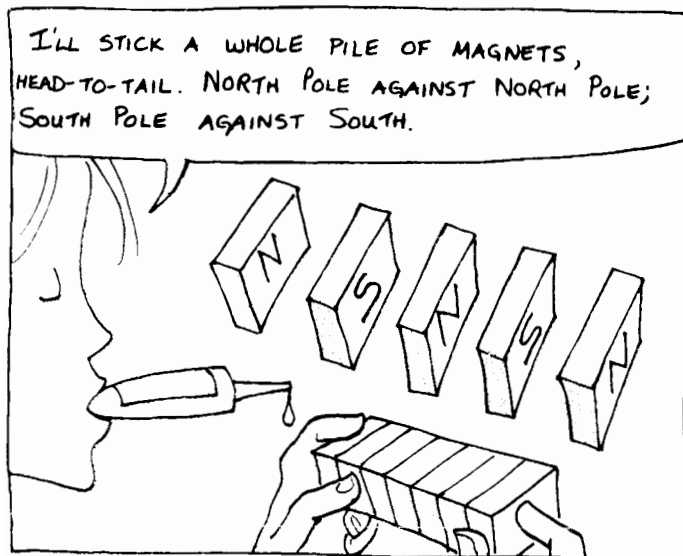
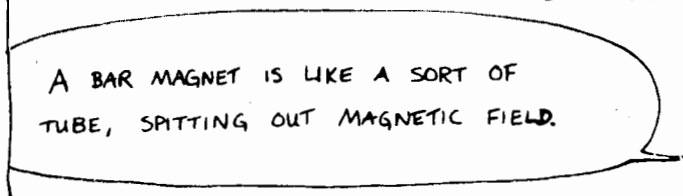
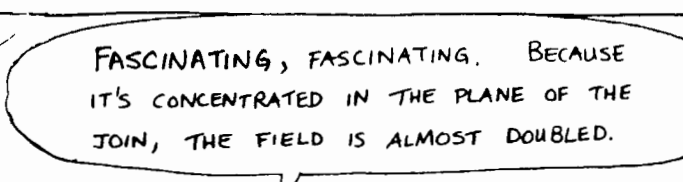
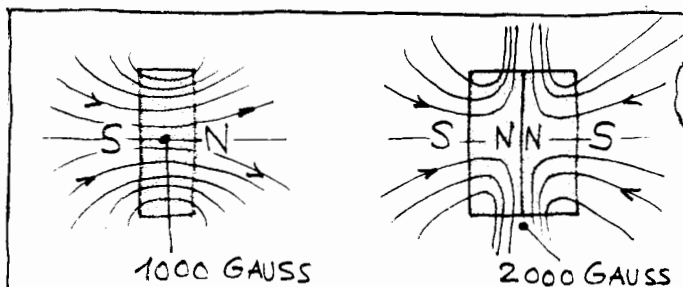
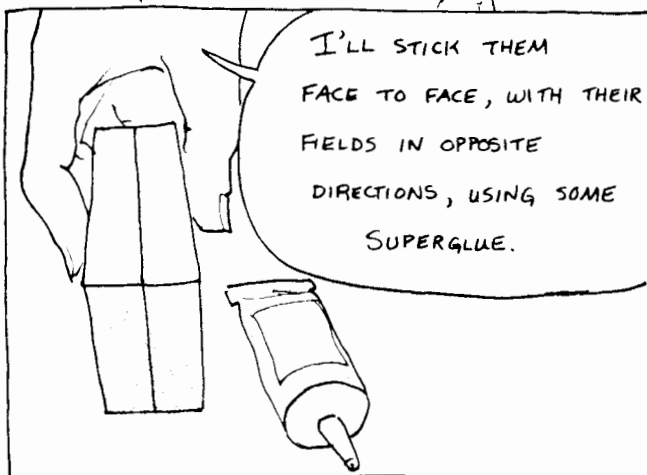
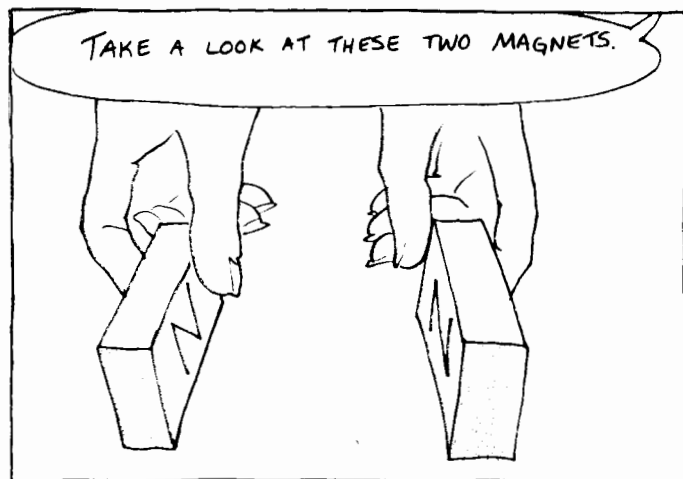
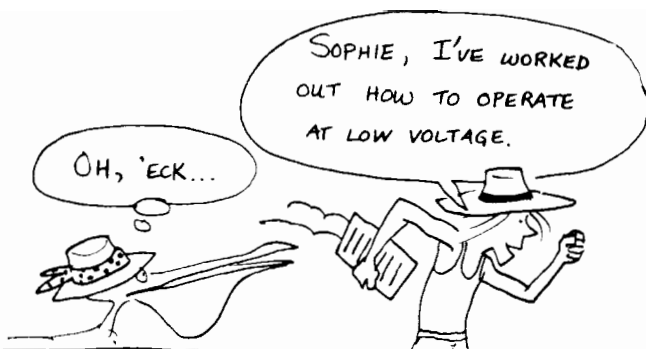
YOUR HYDRODYNE OUGHT TO BE RENAMED THE GYMNOTID. (**)

SO NONE O' THAT 'OLDS ANY WATER, RIGHT?

{(*) SEE APPENDIX C (PAGE 71)

{(**) A GYMNOTID IS A  ABLE TO PRODUCE AN ELECTRICAL DISCHARGE OF 300 VOLTS.

THE PARIETAL ACCELERATOR



HERE'S HOW THE LINES OF FORCE LOOK.

IF THE MAGNETS HAVE THICKNESS d , THEN EVERY d CENTIMETERS THE FIELD INVERTS, LIKE THIS.

AND AT A DISTANCE d FROM THE WALL, THE FIELD IS VIRTUALLY NONEXISTENT.

WATCH, NOW. I'VE ADDED SOME ELECTRODES, LIKE THIS, WITH ALTERNATING POLARITY. NOW, IF I APPLY THE RIGHT-HAND RULE, I SEE THAT I'VE CREATED A FIELD OF FORCES, ALL PARALLEL AND IN THE SAME DIRECTION, NEAR TO THE WALL, OUT TO A DISTANCE d .

FANTASTIC! GEOMETRY AS THE ACCOMPLICE OF PHYSICS!

TO CREATE A MAGNETIC FIELD, YOU NEED ENERGY. BY ACTING ONLY IN A VERY THIN REGION AROUND THE WALL, YOU REDUCE CONSIDERABLY THE VOLUME TO BE MAGNETIZED, HENCE THE ENERGY REQUIRED, WHICH IS PROPORTIONAL.

I CAN ALSO REPLACE THE MAGNETS BY COILS.

HERE'S A SIMPLER
SYSTEM, USING TWO
ELECTRODES.

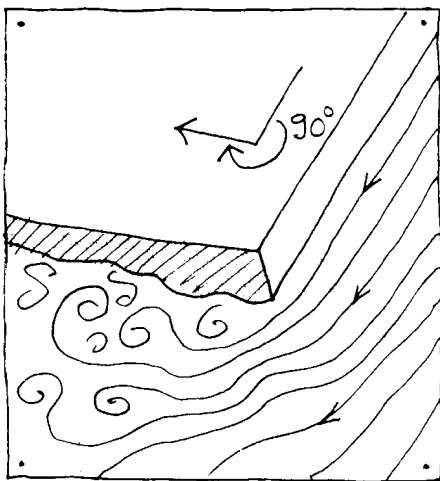
A NEW KIND OF FLUID MECHANICS

WHENEVER YOU MAKE A FLUID DO SOMETHING THAT MOVES IT, IT REACTS. FOR EXAMPLE,
IF YOU TRY TO MAKE IT TWIST TOO ABRUPTLY, IT "COMES UNSTUCK."

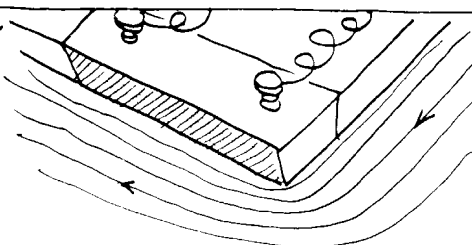
AND IF YOU MOVE AN OBJECT THROUGH THE FLUID TOO QUICKLY,
SO THAT IT DOESN'T HAVE TIME TO "GET ITSELF READY" TO MAKE WAY
FOR IT, THEN WAVE FRONTS APPEAR.

AND THAT'S HOW IT IS IF YOU LET THE FLUID DO AS IT PLEASES.
BUT MHD CHANGES RADICALLY ALL THE PARAMETERS OF THE
PROBLEM.



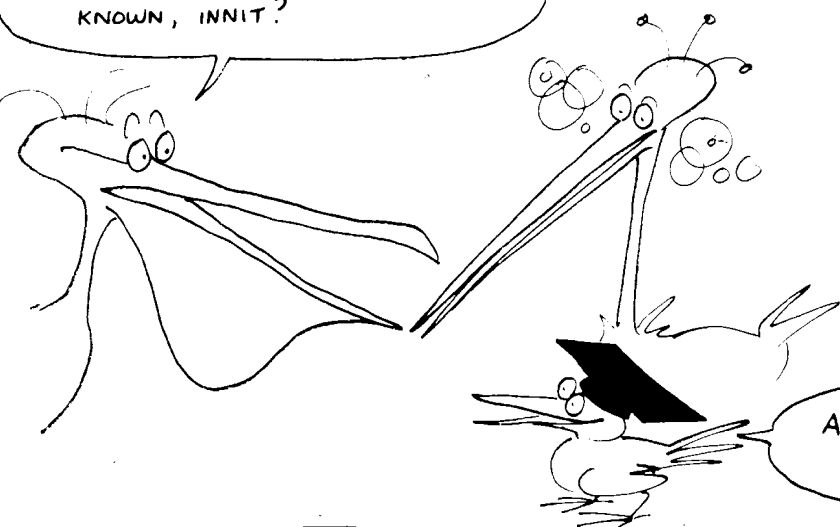


FOR EXAMPLE: IN CLASSICAL FLUID MECHANICS, A SHARP CORNER PRODUCES A LOSS OF ADHESION, GENERATING TURBULENCE.



A LITTLE BIT OF MHD, AND IT'S ALL HUNKY-DORY AGAIN.

BUT... IT'S CRAZY! IT'S ALL KNOWN, INNIT?

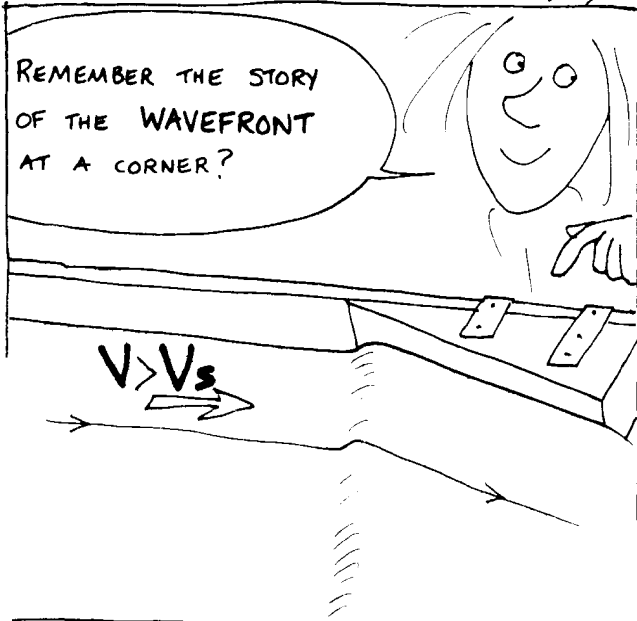


EITHER WAY, YOU WIN!

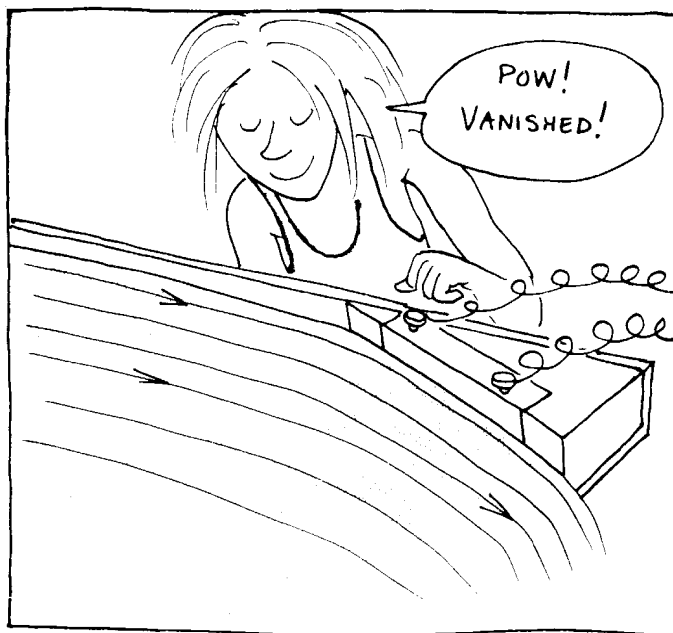


A WHIFF OF MADNESS WAFTS THROUGH THIS TALE...

REMEMBER THE STORY OF THE WAVEFRONT AT A CORNER?



POW! VANISHED!



YOU SEE, IT'S LOOKING
ENTIRELY FEASIBLE TO TAME A FLOW.
WHEREVER THE FLUID STARTS TO SLOW
DOWN, YOU SPEED IT UP AGAIN; AND WHEN
IT RUSHES AHEAD, YOU REIN IT BACK IN.

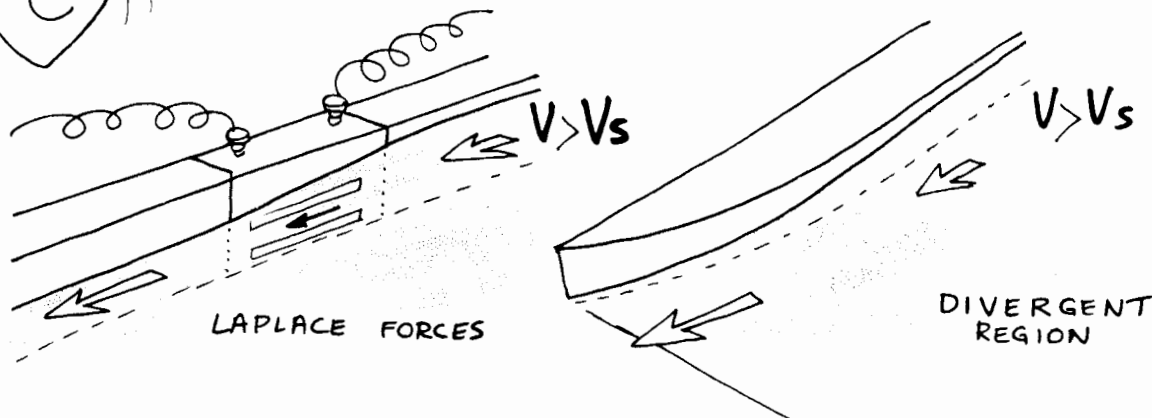
NOTHING ABOUT IT
IN HERE....

GASP!

COMPRESSION WAVES EXPANSION WAVES

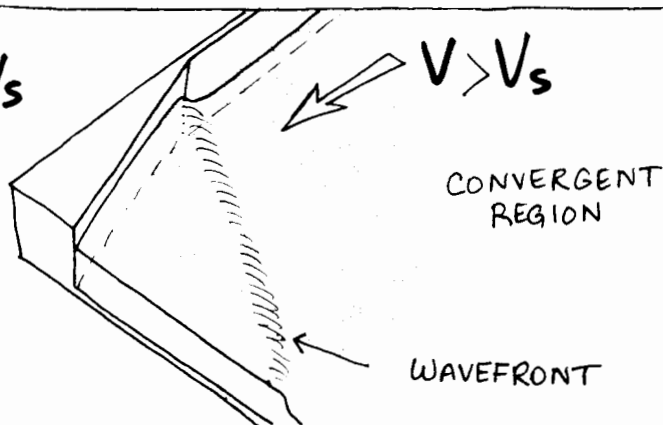
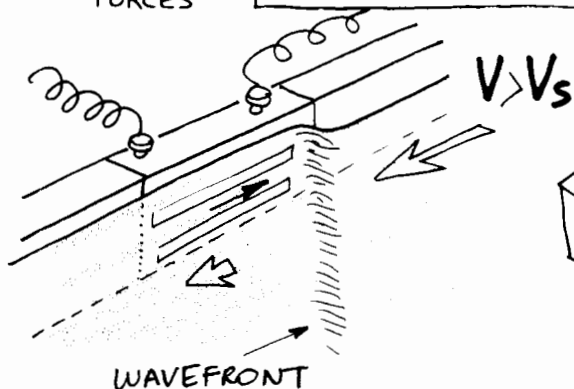
OH YES, LENNY—YOU'LL SEE. YOU AGREE THAT WHEN $V > V_s$, CHANGES
IN DIRECTION OF A WALL CREATE EITHER A COMPRESSION OR AN
EXPANSION. NOW, LOOK, THE MAGNETOHYDRODYNAMIC SYSTEM CREATES
ABSOLUTELY IDENTICAL EFFECTS!

THE MHD ACCELERATOR, OR A DIVERGENT REGION, LEAD TO
A LOWERING OF THE LEVEL OF THE WATER IN THE CANAL.



LAPLACE
FORCES

THE MHD DECELERATOR, OR A CONVERGENT REGION, LEAD
TO A RISE IN THE LEVEL OF WATER IN THE CANAL.

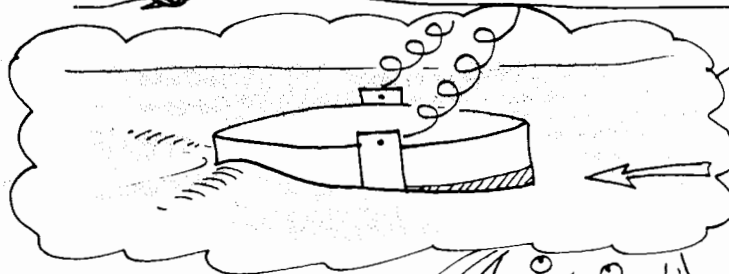


SO IT OUGHT TO BE POSSIBLE TO ARRANGE FOR THE MUTUAL
ANNIHILATION OF THE PHENOMENA OF COMPRESSION AND EXPANSION
BY CANCELLING THOSE OF "NATURAL" ORIGIN — DUE TO THE WALLS—
AGAINST LAPLACE FORCES OF "ARTIFICIAL" ORIGIN.



TO REGULARIZE THE FLOW AROUND THE HULL, YOU MUST SMOOTH OUT,
AS FAR AS POSSIBLE, ANY VARIATIONS IN THE WATER LEVEL. WHERE
A WAVEFRONT TENDS TO FORM, I ACCELERATE. AND TO AVOID AN
OVEREXPANSION, AN OVERACCELERATION, IN SOME REGIONS,
I SLOW IT DOWN.

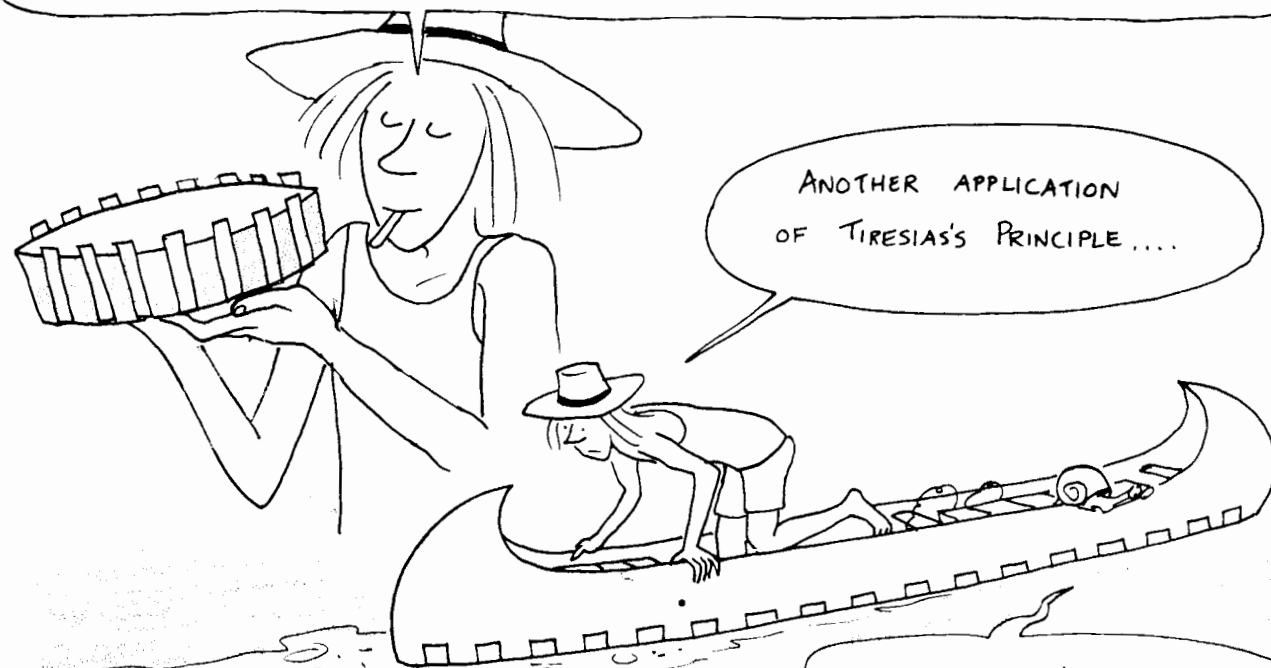
IT'S AN APPLICATION OF MY FUNDAMENTAL PRINCIPLE, PURE
AND SIMPLE: PLEASE LEAVE THE FLUID IN THE STATE
IN WHICH YOU WOULD WISH TO FIND IT.



IN MY EXPERIMENT ON PAGE 28
I SUCCEEDED IN ANNIHILATING THE
BOW WAVE. BUT THE STERN WAVE
REMAINED— IN FACT IT WAS REINFORCED.

THE STERN WAVE OCCURRED PRECISELY BECAUSE YOU LOWERED THE WATER
LEVEL TOO MUCH WHEN YOU ACCELERATED IT.

YOU'RE RIGHT. THE MAIN OBJECTIVE SHOULD BE TO KEEP THE HEIGHT OF THE WATER CONSTANT, AT THE NATURAL FLotation LINE. TO DO THAT, I'LL NEED A WHOLE MASS OF ELECTRODES, SOME ACCELERATING, SOME RETARDING.



ANOTHER APPLICATION OF TIRESIAS'S PRINCIPLE....

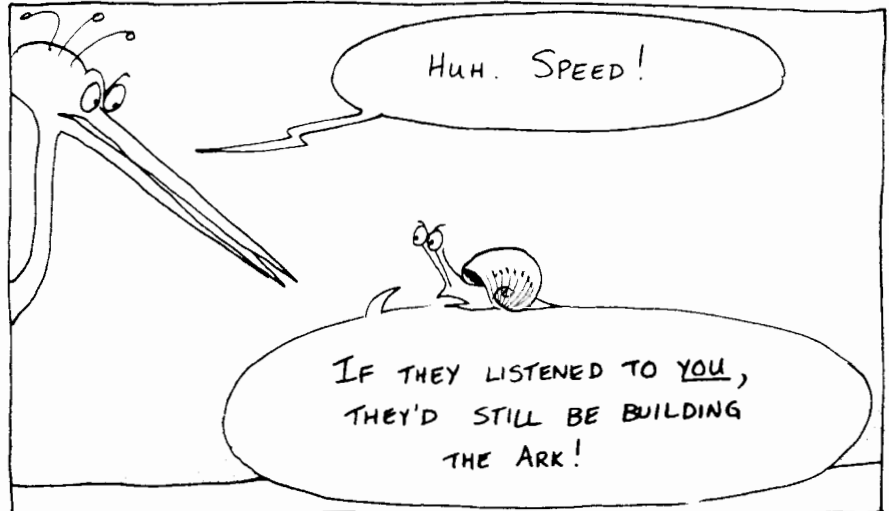
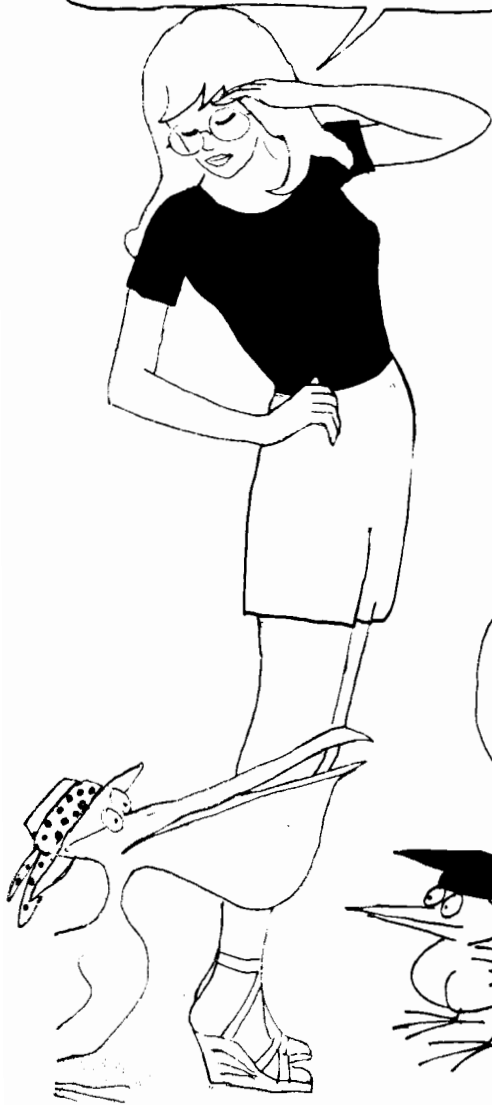
THAT'S RIGHT! SORT IT ALL OUT SO THAT YOU LEAVE THE FLUID IN THE STATE IN WHICH YOU WOULD WISH TO FIND IT... NO STERN WAVE!

BLOOMIN' MARVELOUS. TWENNY TESLAS WOLF O' MAGNETIZATION, AN' ARCHIE'S KERNOO SKIMS FRU THE WATER WIVAHT WAVEFRONTS AN' WIVAHT ANY TURBULENCE. NO DAMAGE TER LANDIN' STAGES. WOT NEXT?

WOULDN'T IT BE EASIER JUST TO STAY FAR ENOUGH OUT TO SEA? DON'T YOU ALL HAVE MORE IMPORTANT THINGS TO DO?



I DON'T AGREE. I THINK WE OUGHT TO TAKE A GOOD LOOK AT ARCHIE'S IDEA, ESPECIALLY THE PARIETAL ACCELERATOR. ALL BOATS SUFFER A LOT FROM HYDRODYNAMIC DRAG - RESISTANCE TO FORWARD MOTION DUE TO FRICTION OF THE WATER AGAINST THE HULL. NOW THE PRESENCE OF WAVEFRONTS ALTERS THE PRESSURE DISTRIBUTION OVER THE CONTOUR OF THE HULL, LEADING TO A WAVE TRAIN IN ITS WAKE, WHICH GROWS RAPIDLY WITH THE SPEED AND THAT MUST BE THE MAIN FACTOR LIMITING THE SPEED AT WHICH THE BOAT CAN TRAVEL.



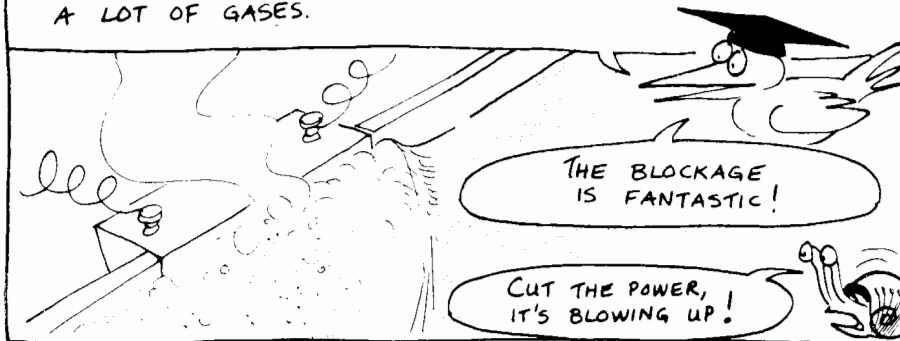
WE KNOW ROUGHLY HOW MUCH ENERGY MUST BE BROUGHT INTO PLAY TO SUPPRESS WAVEFRONTS. (*)
THE WORK DONE BY THE LAPLACE FORCES MUST BE AT LEAST THE INCIDENT KINETIC ENERGY OF THE FLUID.



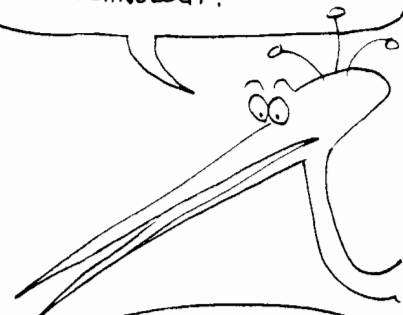
MMMM... SO IF THE BOAT GOES AT A SPEED V , THEN THE LAPLACE FORCE **IB** MUST EXCEED SOME DEFINITE THRESHOLD. (*)

(*) SEE APPENDIX B (PAGE 71)

IT'S BEST TO MAKE THE MAGNETIC FIELD B AS LARGE AS POSSIBLE. IF YOU HAVE B SMALL AND COMPENSATE BY MAKING I LARGE, THEN FIRST THE EFFICIENCY IS LOW, AND SECOND, ELECTROLYSIS WILL OCCUR, GIVING OFF A LOT OF GASES.

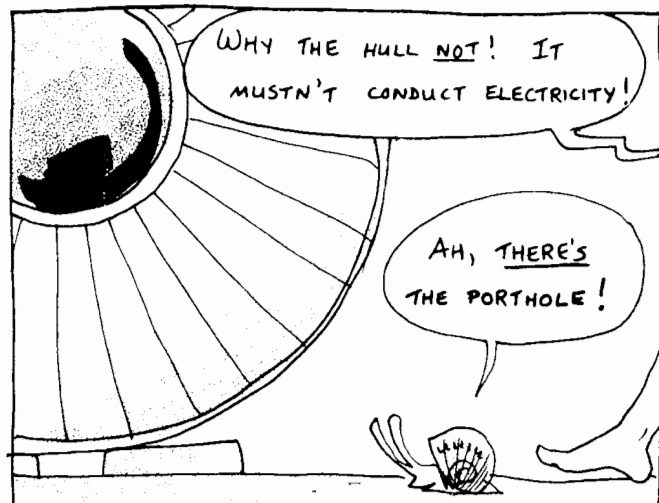
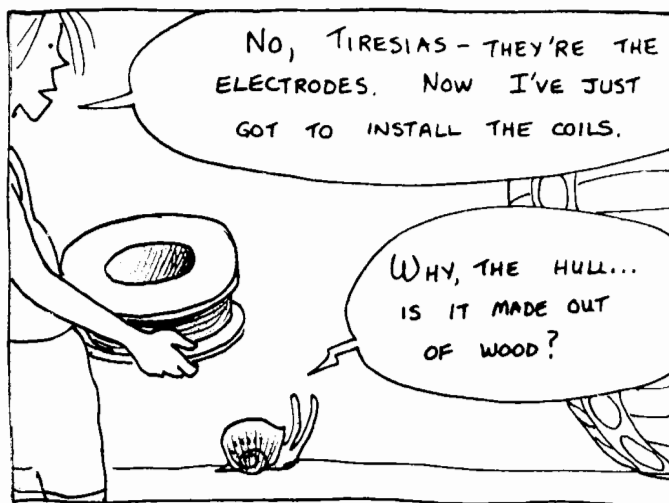
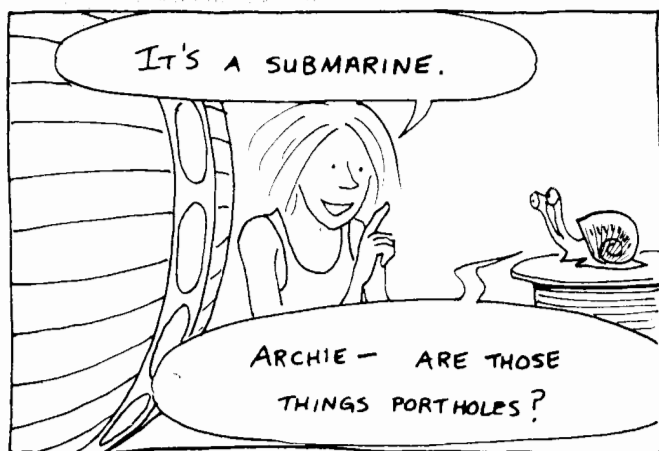


DON'T YOU FEEL THAT ALL THIS... ER... ELECTROMAGNETIC PROPULSION IS JUST A LITTLE BIT ADVANCED FOR THE CURRENT STATE OF TECHNOLOGY?

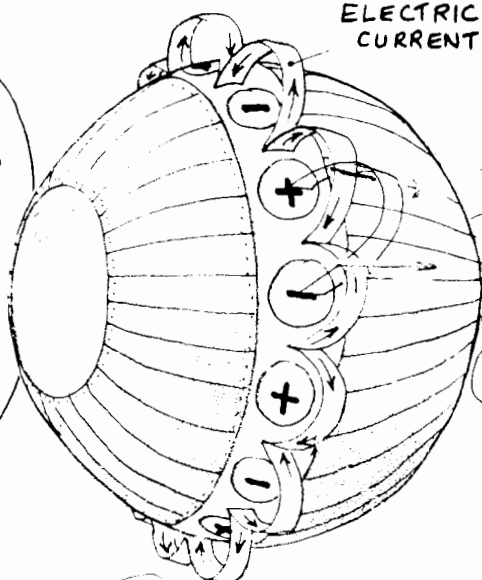


WE JUST NEED TO INNOVATE, THAT'S ALL!

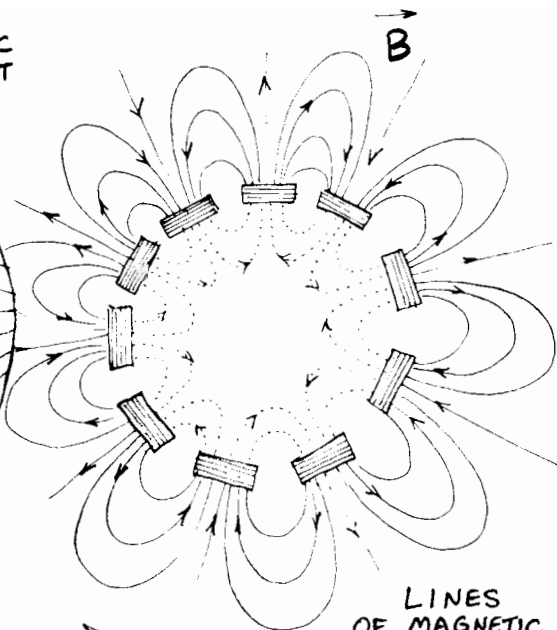
THE SCREWLESS SUBMARINE



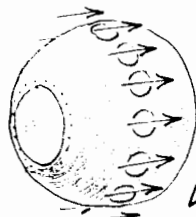
SEE, IF YOU
APPLY THE RIGHT-HAND
RULE, YOU CAN WORK
OUT THAT THE DEVICE
PRODUCES A FIELD OF
LAPLACE FORCES SUITABLE
FOR PROPULSION.



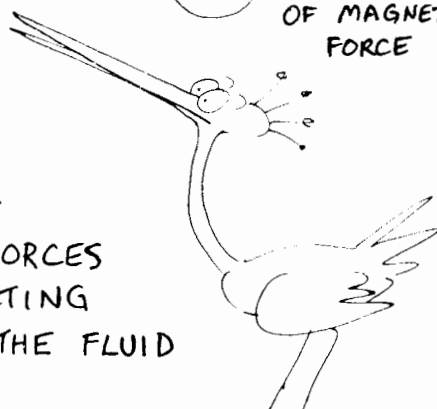
ELECTRIC
CURRENT



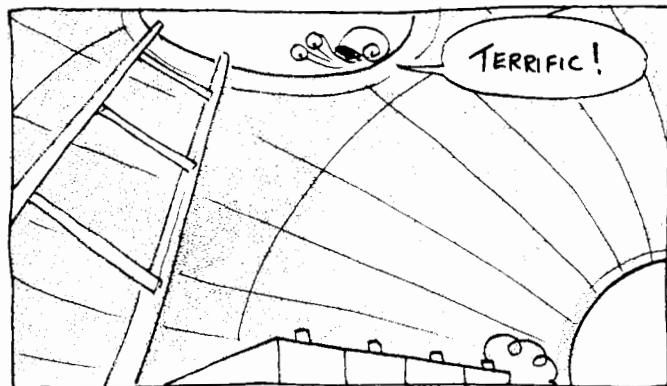
LINES
OF MAGNETIC
FORCE



FORCES
ACTING
ON THE FLUID



YER'LL NEVER GET ME IN ONE
O' THEM FINGS!

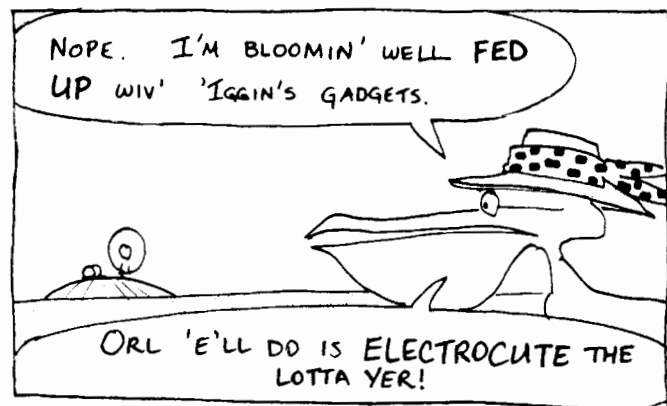


TERRIFIC!



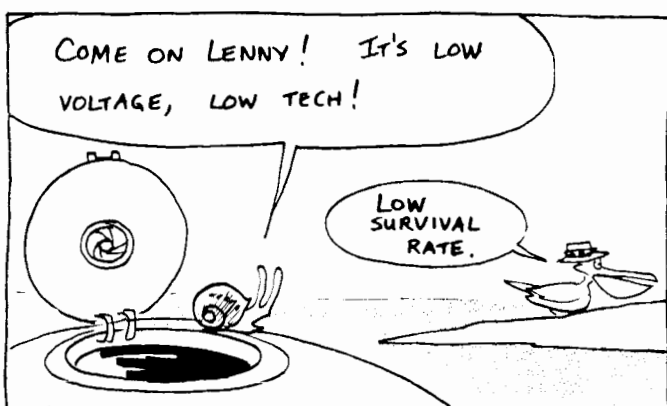
COME ON, LENNY!
STOP MAKING FACES!

WE'RE GOING TO
TRY OUT THE
HYDRODYNE.



NOPE. I'M BLOOMIN' WELL FED
UP WIV 'IGGIN'S GADGETS.

ORL 'E'LL DO IS ELECTROCUTE THE
LOTTA YER!



COME ON LENNY! IT'S LOW
VOLTAGE, LOW TECH!

LOW
SURVIVAL
RATE.

I DUNNO 'OW YOU FEEL ABAHT IT... BUT TER ME, IT'S ORL JUST A TINY BIT DUBIOUS

ME TOO.

HOW DO YOU STEER IT?

SIMPLE: YOU FIDDLE WITH THE INTENSITIES OF THE ELECTRODES.

TURN...

... STOP...

... OR GO INTO REVERSE.

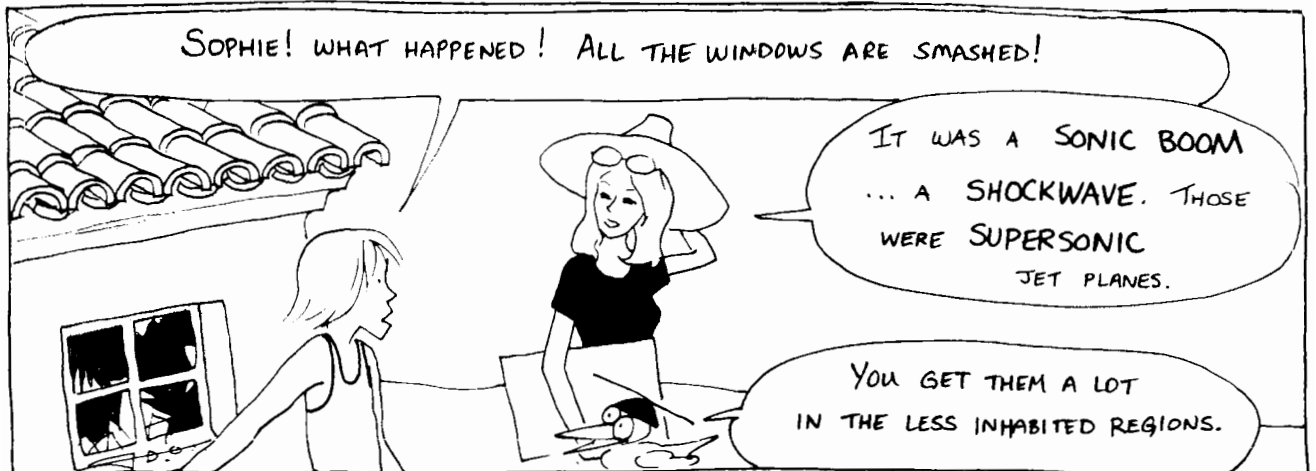
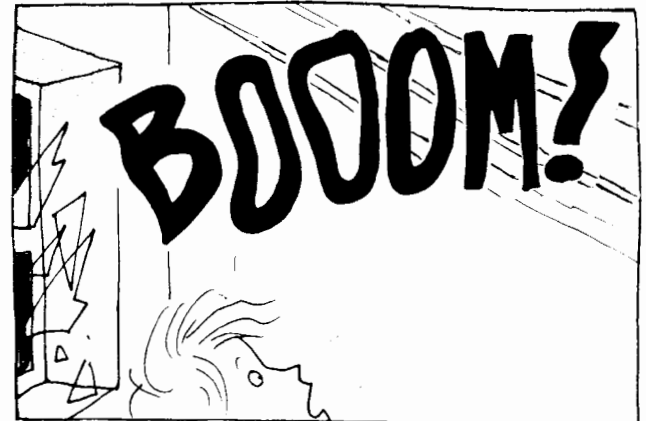
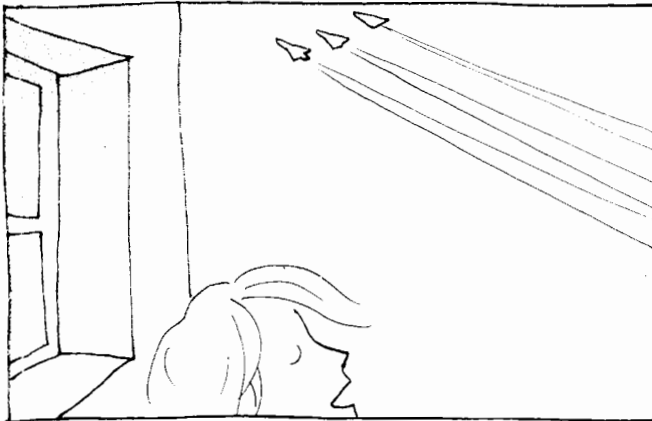
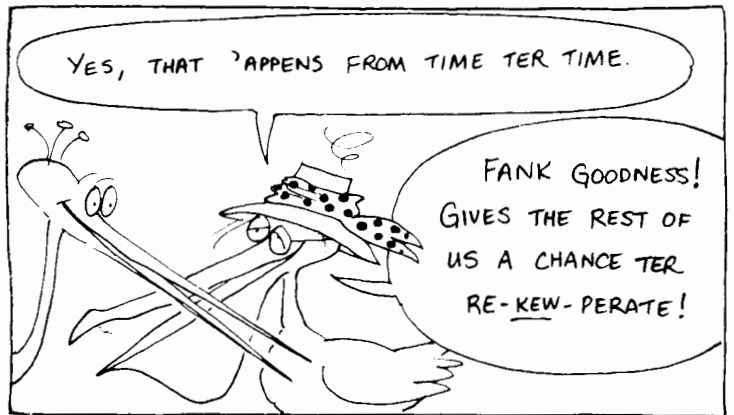
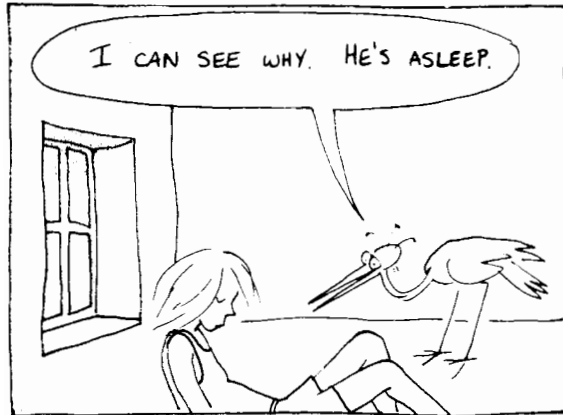
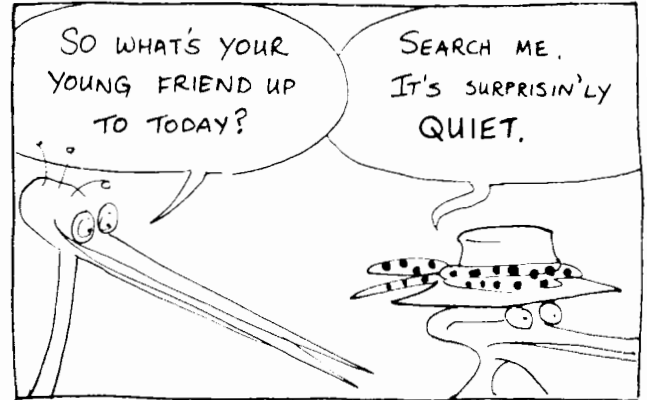
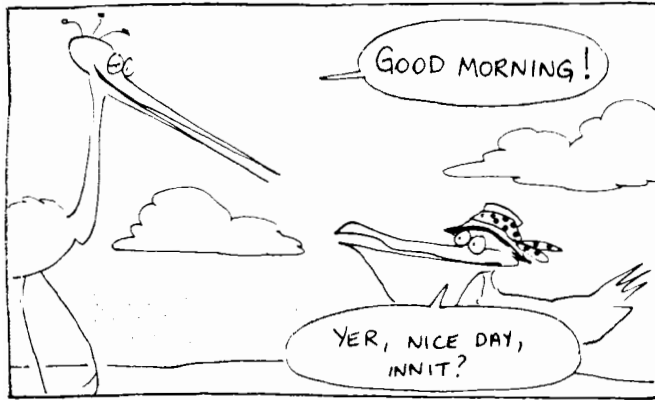
AN MHD SUBMARINE COULD BE VERY QUICK AND COMPLETELY SILENT.

DRAT!

THAT'S HOW IT GOES, MY DEAR LENNY. WHEN WE GET EFFECTIVE SUPERCONDUCTING MAGNETS (*) AND ULTRAEFFICIENT ELECTRICAL GENERATORS, BOATS WILL STOP MAKING WAVES, AND SUBMARINES WILL BLOW BUBBLES.

(*) A SUPERCONDUCTING MATERIAL, COOLED TO VERY LOW TEMPERATURE (A FEW DEGREES KELVIN) CONDUCTS CURRENT WITHOUT ANY DISSIPATION BY HEATING. NO JOULE EFFECT.

THE FOLLOWING DAY



SUPERSONIC FLOW

- THE SHOCKWAVE THAT BROKE THE WINDOWS IS VERY SIMILAR TO THE BOW WAVE THAT SMASHED UP YOUR LANDING-STAGE.

- YOU MEAN, AIRPLANES MAKE WAVES?

- IN A MANNER OF SPEAKING, YES. BUT THEY DON'T MAKE SURFACE WAVES; THEY EMIT SOUND WAVES, WHICH TRAVEL AT THE SPEED OF SOUND V_s . (*) WHEN A BOAT

TRAVELS AT A SPEED V GREATER THAN V_s IT PRODUCES WAVEFRONTS. BUT WHEN A PLANE TRAVELS FASTER THAN SOUND (GREATER THAN V_s) IT PRODUCES SHOCKWAVES.

- HOW CAN IT, WHEN THERE'S NO FREE SURFACE?

- THE DENSITY OF THE AIR PLAYS THE ROLE OF THE HEIGHT OF THE WATER.

SURFACE WAVES TEND TO MAINTAIN A CONSTANT HEIGHT. SIMILARLY, SOUND WAVES TEND TO MAINTAIN A CONSTANT DENSITY.

SHOCKWAVES ARE THE FRONTS WHERE DENSITY, PRESSURE, AND TEMPERATURE ARE MUCH HIGHER.



YOU CAN COMPARE THE MOTION OF MOLECULES TO A LOT OF BLINDFOLDED PEDESTRIANS, WANDERING ABOUT AT A SPEED V_s IN A TOTALLY DISORDERED FASHION, IN ONE PLACE, CONTINUALLY BUMPING INTO EACH OTHER (MOLECULAR COLLISIONS). AN OBJECT PENETRATING A GAS IS SIMILAR TO A BUS, RUNNING INTO THE CROWD AT A SPEED V . IF THIS IS LESS THAN V_s , THEN INFORMATION CAN PASS UPSTREAM (FORWARD). THE PEDESTRIANS, WARNED OF THE VEHICLE'S ARRIVAL BEFORE IT REACHES THEM, CAN MAKE WAY FOR IT. THAT'S ONE WAY TO VISUALIZE SUBSONIC FLOW.

(*) SEE FLIGHT OF FANCY, SAME SERIES.

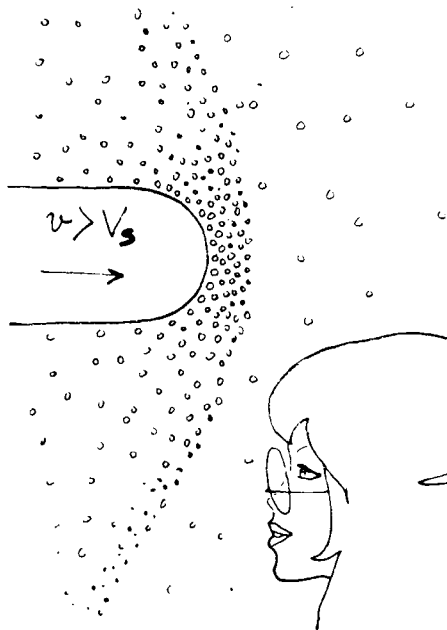
BUT WHAT HAPPENS WHEN V IS GREATER THAN V_s ?



THE PEDESTRIANS - THE MOLECULES - ARE NO LONGER ABLE TO AVOID THE OBJECT BEFORE IT REACHES THEM, SO MAINTAINING A CONSTANT DENSITY. SO THE GAS (CROWD) TENDS TO ACCUMULATE AHEAD OF THE OBJECT, FORMING A SORT OF MOUND - AN ABRUPT INCREASE IN DENSITY.



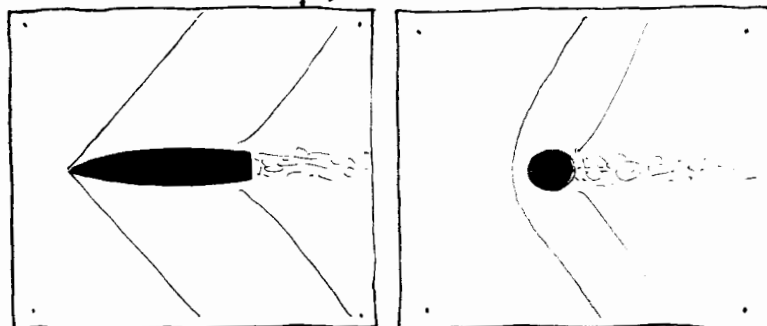
SHOCKWAVES



THIS PHENOMENON IS CALLED A SHOCKWAVE. HERE SOUND WAVES REPLACE SURFACE WAVES, OTHERWISE IT'S JUST THE SAME AS FOR A BOW WAVE. FRONTS OF DENSITY, PRESSURE, AND TEMPERATURE ARE INEVITABLY FORMED. THE SHOCKWAVE OCCURS WHEN THE SPEED V OF THE FLOW IS GREATER THAN THE SPEED OF SOUND V_s .

YOU MEAN TO SAY THAT EVERY TIME THOSE HOTSHOTS AT THE AIR FORCE BASE DECIDE TO AMUSE THEMSELVES WITH SOME HIGH-SPEED AEROBATICS, I HAVE TO LUG A HEAP OF REPLACEMENT WINDOWS AROUND THE HOUSE!

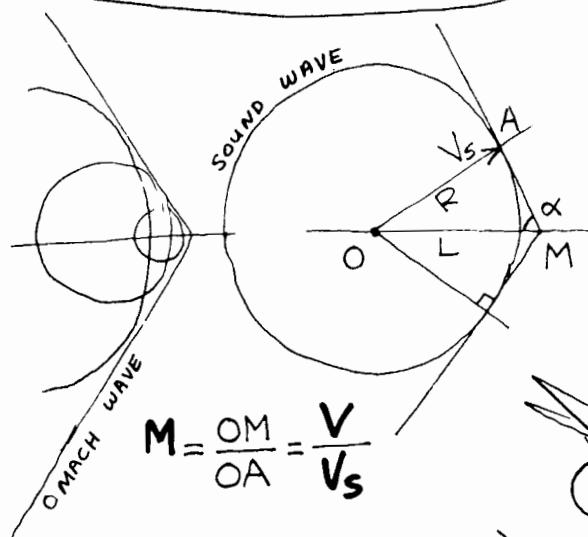
YEAH, THAT FIGURES!



SO EVERY OBJECT TRAVELING AT A SUPERSONIC SPEED (FASTER THAN SOUND) WILL HAVE A **FRONTAL SHOCKWAVE** AND A **REAR SHOCKWAVE**. ON THE LEFT IS A BULLET, ON THE RIGHT A SPHERE.

EVERY OBJECT, EVEN A GRAIN OF SAND, PROJECTED AT A SPEED $V > V_s$, CREATES A SHOCK. THE RATIO $M = V/V_s$ IS CALLED THE **MACH NUMBER**.

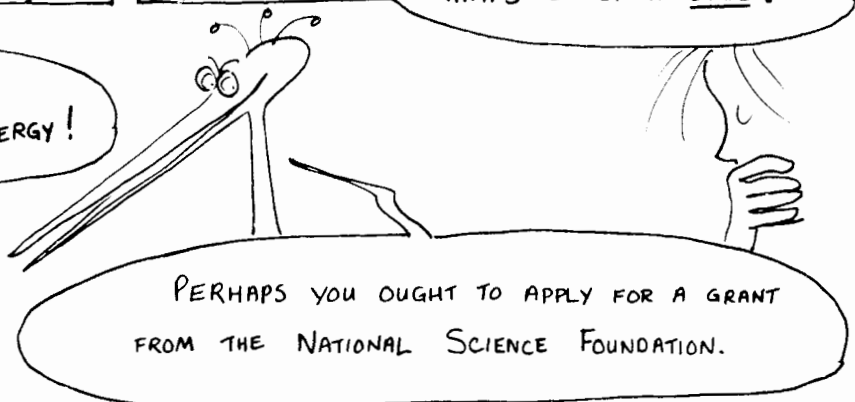
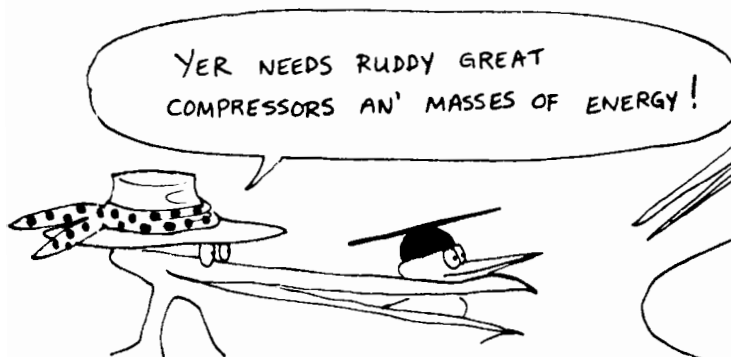
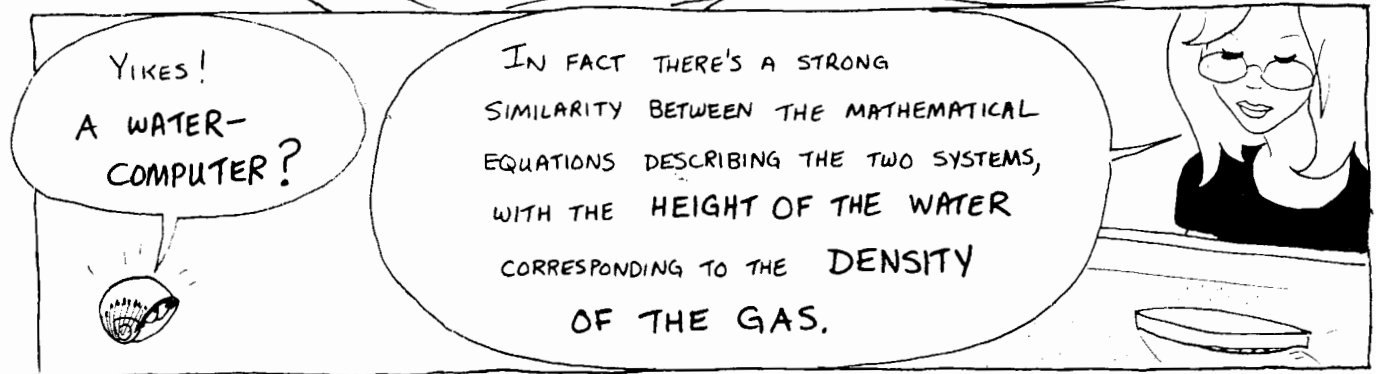
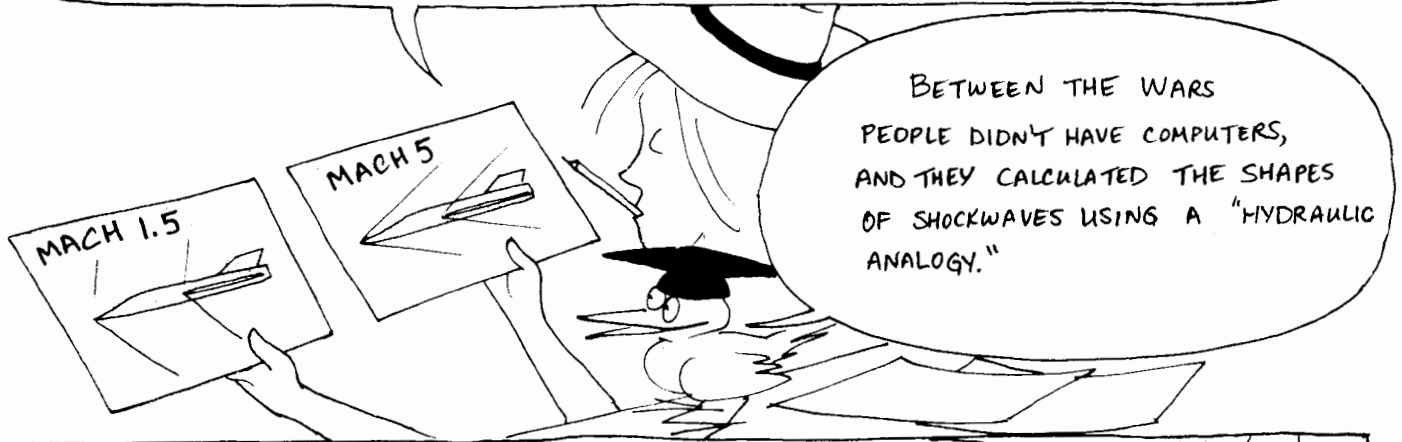
AND IF THE OBJECT IS VERY SMALL, THE SHOCKWAVE IS CALLED A **MACH WAVE**. (*)



(*) SEE APPENDIX A (PAGE 71).



SOPHIE'S RIGHT, YOU KNOW, MAX. THE FLOW OF A LIQUID WITH A FREE SURFACE CLOSELY RESEMBLES THE SUPERSONIC FLOW OF A GAS. I THINK WE'D BETTER TAKE ANOTHER LOOK AT PAGE 15 TO REMIND OURSELVES ABOUT THE EFFECT OF SLOWER OR FASTER MOTION ON THE SHAPE OF THE SHOCK.



THE SOUND BARRIER

THE HEAT BARRIER

WITH A SUPERSONIC WIND-TUNNEL, IT'S POSSIBLE TO OBSERVE A NUMBER OF DIFFERENT PHENOMENA. PRIMARILY, THE PASSAGE THROUGH THE SOUND BARRIER ($V = V_s$), ACCOMPANIED BY THE APPEARANCE OF A WAVE TRAIN WHICH IS SUPERIMPOSED ON THE TRAIN DUE TO FRICTIONAL DRAG.

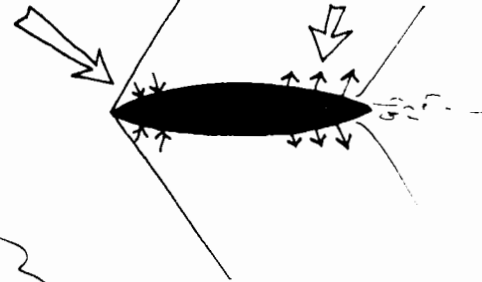


WHAT'S THAT IN CONCRETE TERMS?



COMPRESSION

EXPANSION



$V > V_s$

IN HYDRODYNAMICS, THE APPEARANCE OF WAVEFRONTS AFFECTS THE BALANCE OF PRESSURES ON THE HULL, REDUCING THE EFFICIENCY. IT'S THE SAME IN SUPERSONIC AERODYNAMICS.

IT'S NOISY, IT'S USELESS, AND IT WASTES ENERGY.



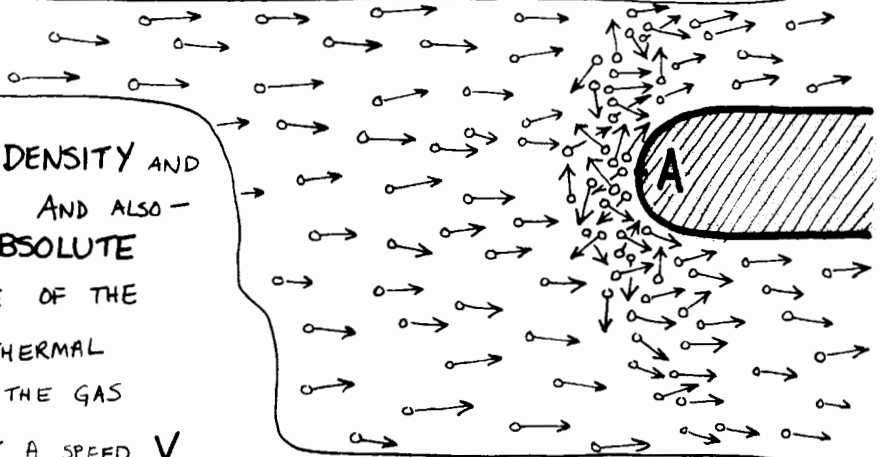
DESPITE ITS SLIM SHAPE, DESIGNED TO REDUCE THIS WAKE, THE CONCORDE SPENDS 40% OF ITS ENERGY CREATING SHOCKWAVES.



IF YOU WANTED TO OVERFLY AN INHABITED REGION AT LOW ALTITUDE AT MACH 5 OR 6, EVERYBODY'S ROOF WOULD FALL IN.



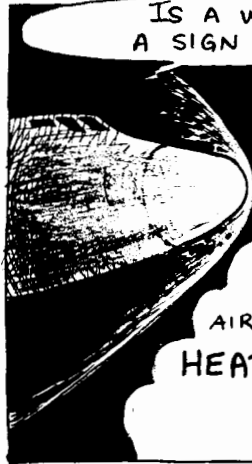
LIKE THE BOW WAVE DEMOLISHED THE LANDING-STAGE!



ACROSS A SHOCKWAVE, THE DENSITY AND PRESSURE INCREASE DRAMATICALLY. AND ALSO - THE TEMPERATURE. THE ABSOLUTE TEMPERATURE IS A MEASURE OF THE KINETIC ENERGY $\frac{1}{2}mv^2$ OF THERMAL AGITATION OF MOLECULES. IF THE GAS

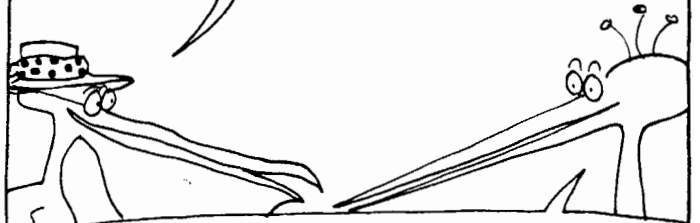
"COLLIDES" WITH AN OBJECT AT A SPEED V , THEN AT THE STATIONARY POINT A (WHERE THE GAS STOPS COMPLETELY) ALL OF THIS ENERGY IS CONVERTED INTO THERMAL AGITATION. SO AT THE POINT A THE STOPPING TEMPERATURE VARIES AS THE SQUARE OF THE SPEED V .

IS A WARM NOSE A SIGN OF HEALTH?



THIS PHENOMENON, WHICH ONLY BECOMES NOTICEABLE ABOVE MACH 2, IMPOSES A SERIOUS CONSTRAINT ON AIRCRAFT, KNOWN AS THE HEAT BARRIER.

FER A GIVEN SPEED, THE FICKER THE AIR, THE 'OTTER EVERYFINK GETS.



WHICH MEANS THAT HYPERSONIC SPEEDS AT LOW ALTITUDES ARE AN IMPOSSIBILITY!



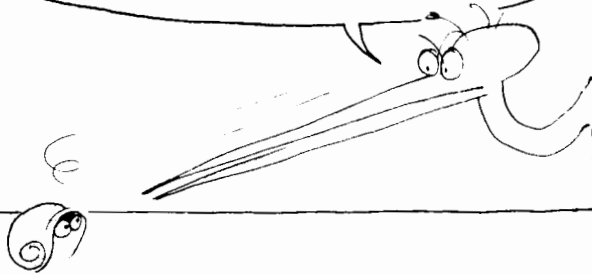
YEAH, SURE. BUT LOW-ALTITUDE SUPERSONIC FLIGHT IS ALL TOO POSSIBLE! ISN'T THERE SOME WAY TO INVENT SUPERSONIC AIRCRAFT THAT DON'T SMASH WINDOWS?...



TO DO THAT, ARCHIE, YOU NEED TO DEVELOP MACHINES THAT DON'T MAKE SHOCKWAVES AT SUPERSOONIC SPEEDS.



AND THAT, MY DEAR CHAP, IS UTTERLY IMPOSSIBLE. IF NOT, THEY'D HAVE DONE IT LONG AGO!



MAYBE, MAYBE.... IF A SHOCK FORMS, IT'S LIKE A BOW WAVE, BECAUSE YOU CAN'T AFFECT THE MOLECULES UPSTREAM BY WAY OF COLLISIONS DUE TO SOUND WAVES FAST ENOUGH FOR THEM TO MAKE WAY. SO THEY CLUMP TOGETHER INTO A KIND OF MOUND, THE SHOCKWAVE.



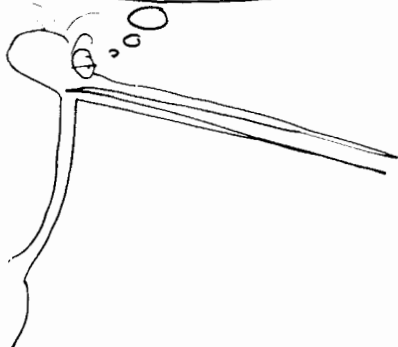
LOGICALLY SPEAKING, THE POSSIBILITY OF ACTING IN ADVANCE BY LAPLACE FORCES SHEDS A NEW LIGHT ON THE PROBLEM OF SHOCKWAVES.



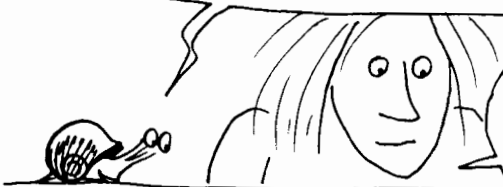
TIRESIAS, TAKE A LOOK AT THIS PHOTO OF THE MHD FLOW ON PAGE 30, ROUND A CYLINDER. WOULDN'T YOU SAY IT'S RATHER SIMILAR TO A SUCTION EFFECT? HMMM...?



BOGGLE BOGGLE.



THAT'S TRUE - IN THE HYDRAULIC EXPERIMENTS YOU MANAGED TO SUCK IN THE WATER UPSTREAM, ENOUGH TO CREATE A DEPRESSION.



THE PROBLEM IS - HOW DO WE EXTEND THE ANALOGY?

← $V > V_s$

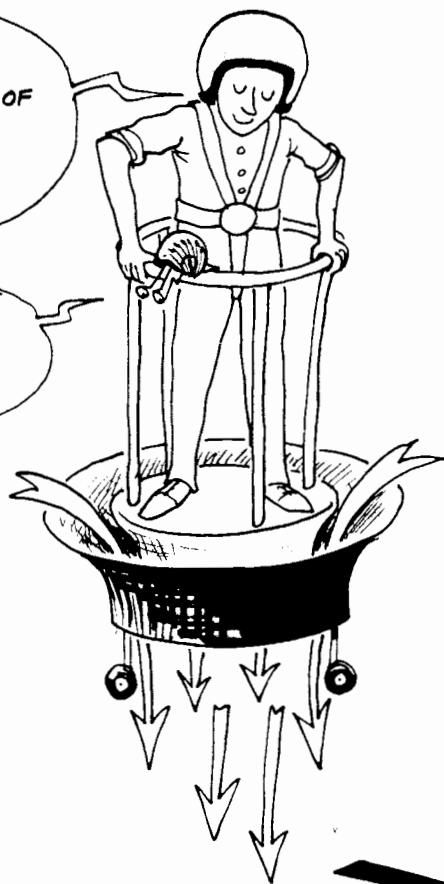
IF THE HYDRAULIC ANALOGY IS ANYTHING TO GO BY, IT LOOKS AS IF THERE ARE THREE METHODS OF FLYING.

WHICH ARE?

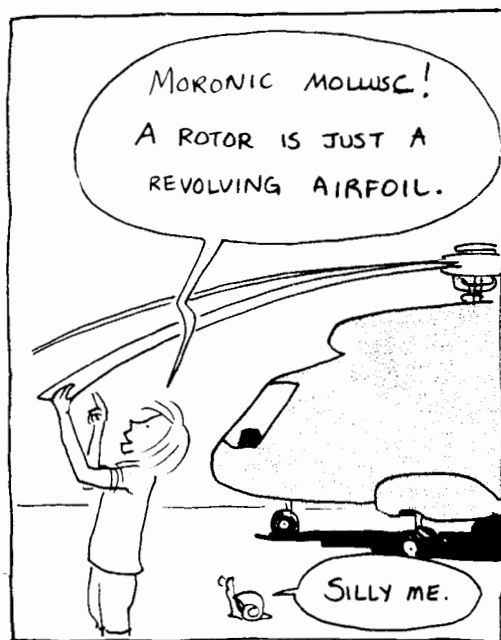
TO FLY, WHATEVER ELSE YOU DO, YOU HAVE TO MAKE THE MOLECULES OF AIR MOVE FROM ABOVE TO BELOW.

FIRST SYSTEM:
I CREATE A MOVEMENT OF
THE GAS USING AN
AIRFOIL.

WHAT AIRFOIL? ALL I
CAN SEE ARE TWO
COUNTERROTATING
ROTORS.



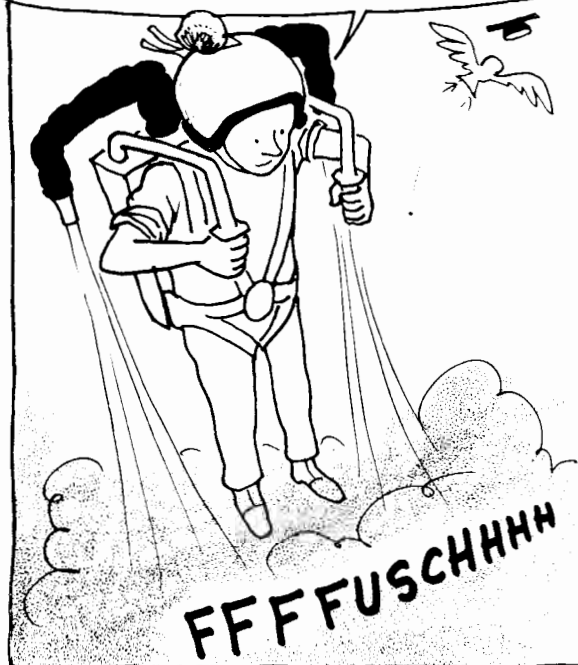
MORONIC MOLLUSC!
A ROTOR IS JUST A
REVOLVING AIRFOIL.



HERE'S HOW TO
OBSERVE THE
INDUCED VELOCITY.



SECOND SYSTEM: ACCELERATE A GAS THAT YOU PRODUCE YOURSELF.



BUT WHAT'S THE THIRD SYSTEM?



TO MY THINKING, IT'S TO SUCK IN THE AIR FROM BELOW USING LAPLACE FORCES.

DID YOU HEAR WHAT I HEARD?

YEAH... ARCHIE AN' TIRESIAS BOFE. IT'S A CRYIN' SHAME!

THEY'VE BOTH GONE COMPLETELY POTTY, THE PAIR OF THEM, I DO DECLARE!

AND SOPHIE, NO DOUBT, AT THE BEACH....

AT LEAST MAX 'AS A BIT 'O SENSE.

WHAT'S UP WITH YOU?

ARCHIE'S GOT SOME CRAZY IDEA IN 'IS 'EAD... ABAHT FLYIN' WIV H'ELECTRICITY.

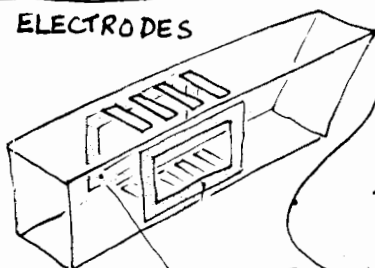
I POINTED OUT TO LENNY MYSELF, JUST NOW, THAT IT'S IMPOSSIBLE, BECAUSE AIR WON'T CONDUCT ELECTRICITY.

IT'S AN INSULATOR.

HOLD YOUR HORSES! THAT DEPENDS ON THE SIZE OF THE ELECTRIC FIELD YOU APPLY. THAT IS, THE RATIO BETWEEN THE TENSION AT THE ELECTRODES AND THE DISTANCE BETWEEN THEM!! IF YOU USE THREE THOUSAND VOLTS PER MILLIMETER, IT CRACKLES AWAY LIKE MAD!

SO WHEN'S THE ELECTRIC CONCORDE COMIN', EH?

ELECTRODES



SOLENOIDS

B

F

YOU SEE, WITH A MAGNETIC FIELD B OF 4 TESLAS (40,000 GAUSS) (*) AND A CURRENT DENSITY OF ONE AMPERE PER SQUARE CENTIMETER (TEN THOUSAND AMPERES PER SQUARE METER) YOU GET A LAPLACE FORCE OF 40,000 NEWTONS PER CUBIC METER. ABOUT FOUR TONS PER CUBIC METER. IF THE MOTOR HAS A USEFUL VOLUME OF ONE CUBIC METER, IT PROVIDES FOUR TONS OF THRUST.

FOUR TONS!

'ANG ON! YER BLINKIN' DREAMIN' AGAIN! THREE THOUSAND VOLTS PER MILLIMETER... THAT'S GETTIN' ON FER A COOL MILLYON VOLTS PER METER!...

FOR LAPLACE FORCES, THAT'S MINDBOGGLING!...

I KNOW A STRIKING APPLICATION OF LAPLACE FORCES.

HMMM? WHAT?

THUNDER.

THUNDER?

I 'OPE YER GOT A REAL BANG OUTTA THAT!

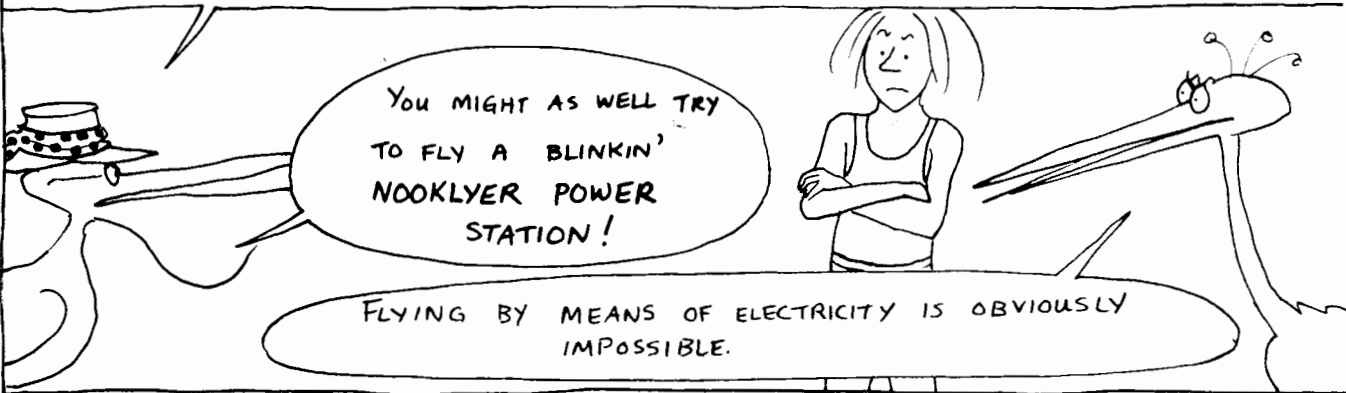


SOPHIE, SOPHIE, COME AND SEE!
ARCHIE'S INVENTING SOMETHING REALLY WAY
OUT! HE'S GOING TO FLY BY ELECTRICITY!

MY GOODNESS,
I'M ON
MY WAY!

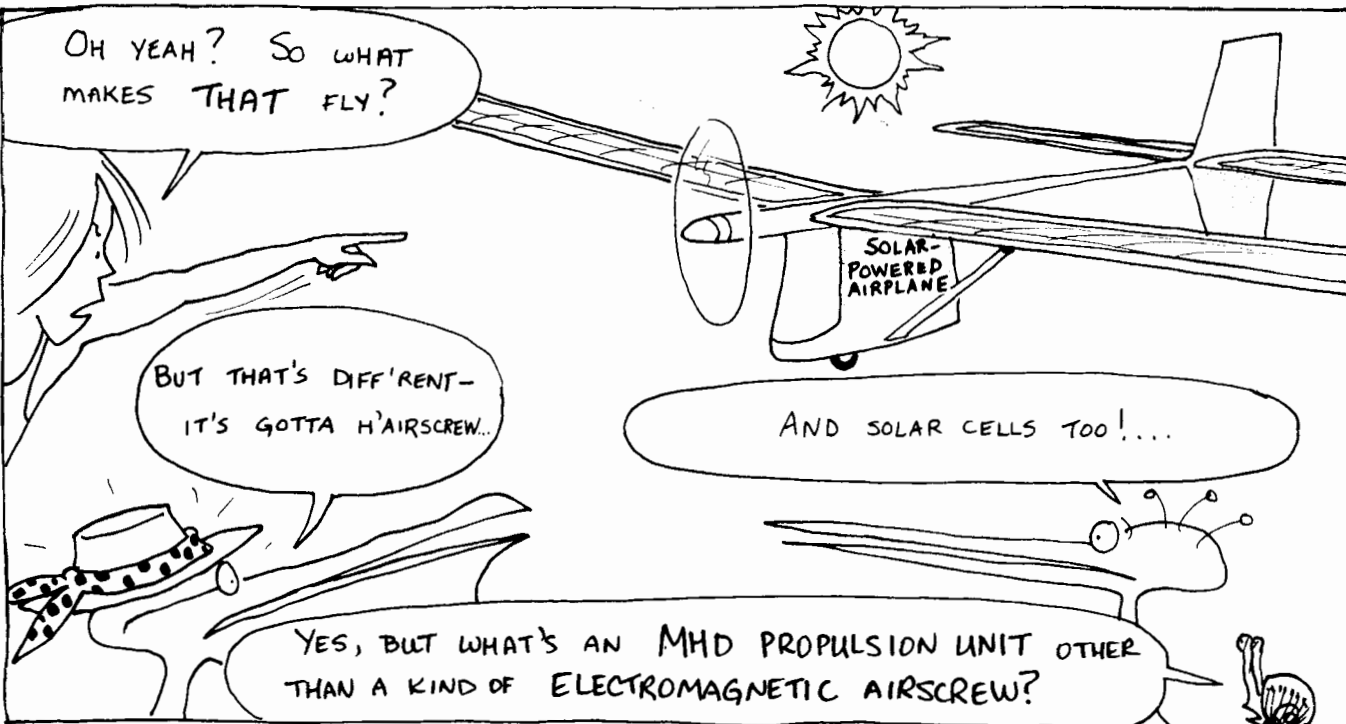
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ACADEMY
OF SCIENCES

D'YER REALIZE 'OW COMPLICATED IT'D 'AVE TER BE? YER'D 'AVE
TER 'AVE A COOLIN' SYSTEM FER THE SOOPACONDUCTERS, AT ULTRALOW TEMPRACHERS
AND A 'LECTRICAL GENNYRATER WOT PUT AHT 'UNDREDS O' MEGAWOTS. H'IMAGINE
THE WEIGHT OF IT ORL!



YOU MIGHT AS WELL TRY
TO FLY A BLINKIN'
NOOKLYER POWER
STATION!

FLYING BY MEANS OF ELECTRICITY IS OBVIOUSLY
IMPOSSIBLE.

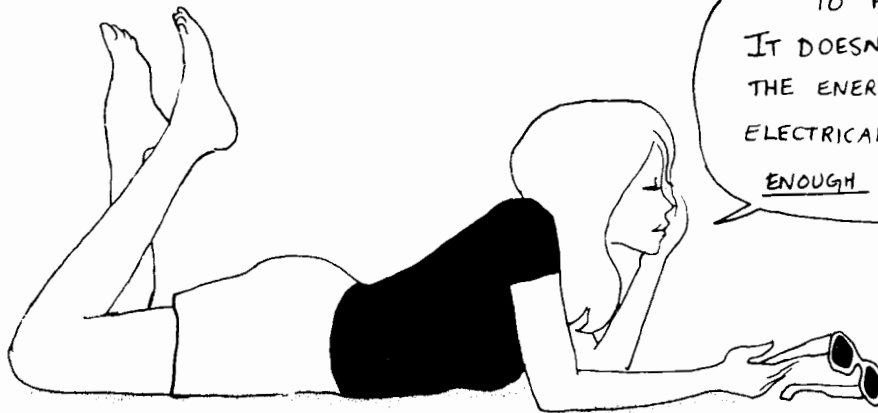


OH YEAH? SO WHAT
MAKES THAT FLY?

BUT THAT'S DIFF'RENT-
IT'S GOTTA H'AIRSCREW...

AND SOLAR CELLS TOO!...

YES, BUT WHAT'S AN MHD PROPULSION UNIT OTHER
THAN A KIND OF ELECTROMAGNETIC AIRSCREW?



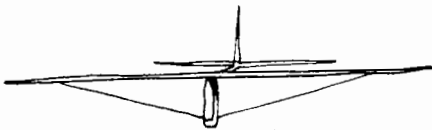
TO FLY, YOU NEED ENERGY.
IT DOESN'T MATTER MUCH WHAT FORM
THE ENERGY TAKES— CHEMICAL,
ELECTRICAL— AS LONG AS THERE'S
ENOUGH OF IT.



WHEN YOU LOOK AT THE BASICS, FLYING IS REALLY JUST A MATTER
OF THE POWER-TO-WEIGHT RATIO FOR A GIVEN SPEED.

40 KM/HR

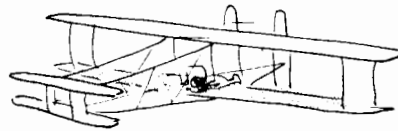
MAN-POWERED
PLANE
(OR ELECTRIC)



10 WATTS PER KILOGRAM

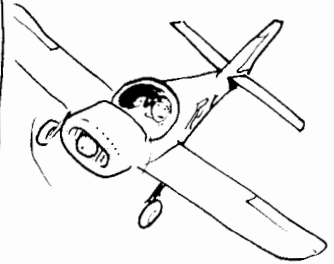
60 KM/HR

THE WRIGHT
BIPLANE
(LOW-TECH)



100 WATTS PER KILOGRAM

250 KM/HR
LIGHT AIRCRAFT



300 WATTS PER
KILOGRAM

700 KM/HR

WORLD WAR II FIGHTER
PLANE



800 WATTS PER KILOGRAM

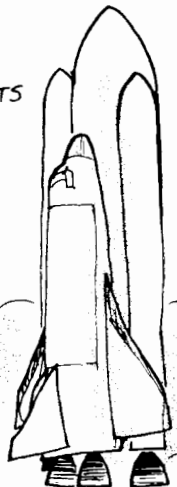
2700 KM/HR

FIGHTER PLANE OF THE
NEXT (AND LAST) WORLD
WAR



5000 WATTS PER KILOGRAM

20,000 WATTS
PER KILOGRAM



THE SPACE SHUTTLE!



'ANG ON, 'ANG ON, 'OLD YER 'ORSES. DON'T A NOOKLYER POWER STATION PRODUCE A KILLERWOT O' H'ELECTRICKLE H'ENERGY PER KILLERGRAM? BY YOUR ARGUMENT H'IT OUGHTA TAKE OFF OF ITS OWN ACCORD!

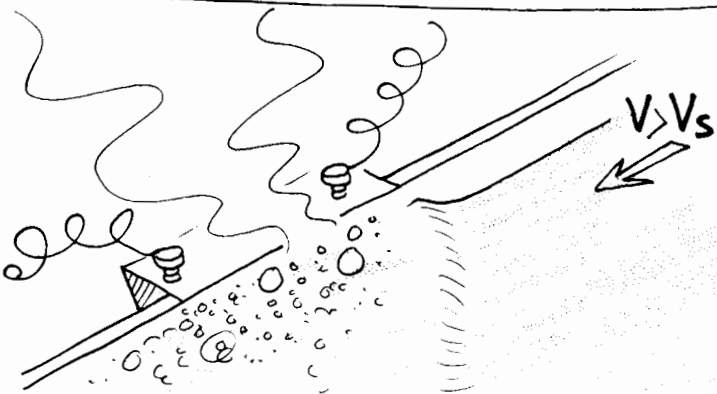
TEN TONS FOR A HUNDRED MEGAWATTS — IT'S IMPOSSIBLE!

WELL?
SOPHIE?

CONFOUND THAT HIGGINS! IT'S FINALLY BEGINNING TO LOOK AS IF YOU'VE GOT TO EXTEND TO GASES THE IDEA WE REACHED FOR FLOWS OF A LIQUID WITH A FREE SURFACE: THE INTERACTION CRITERION AND ITS EFFECTS ON MHD EFFICIENCY. THERE MUST BE A SNAG SOMEWHERE — I WONDER WHAT IT IS?

WELL?

IN THE EXPERIMENT ON PAGE 43, TOO STRONG AN APPLICATION OF ENERGY PRODUCED A BLOCKAGE.

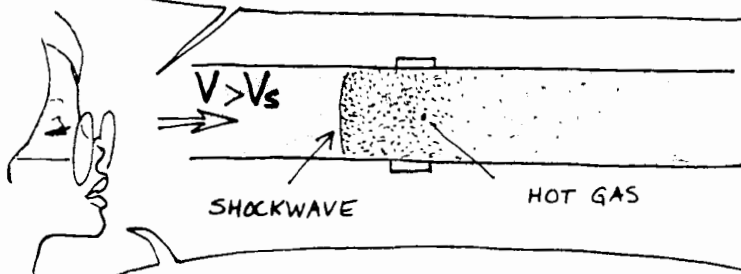


THERMAL BLOCKAGE

IS IT POSSIBLE THAT A SIMILAR PHENOMENON IN A GAS MIGHT PREVENT THE MHD ACTION?



IN FACT, YOU CAN BLOCK A SUPERSONIC FLOW OF A GAS BY WAY OF HEAT, VIA THE JOULE EFFECT. IN A PURELY ELECTRICAL DISCHARGE (NO MAGNETIC FIELD) THE BUBBLE OF HOT GAS BEHAVES LIKE A TRAFFIC JAM, AND A SHOCKWAVE FORMS.

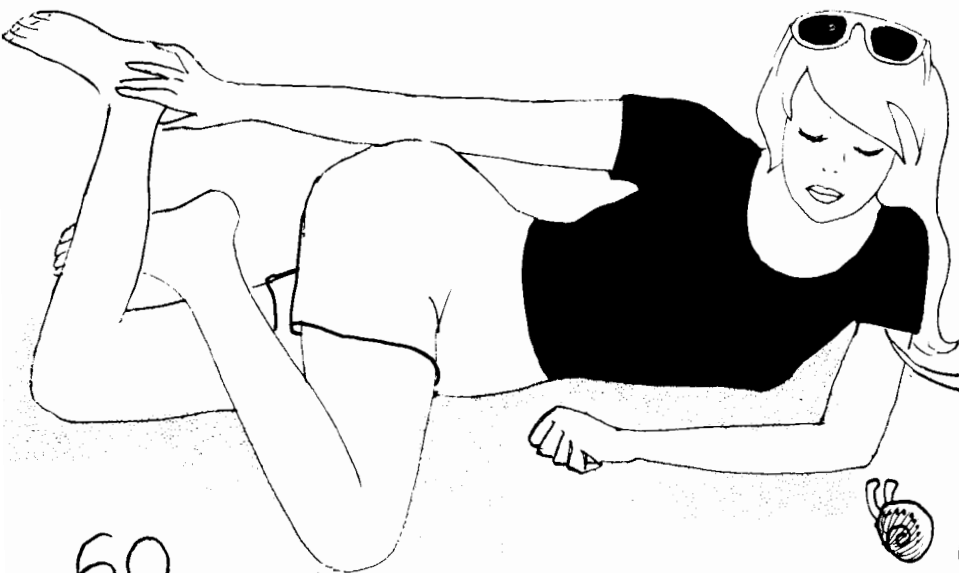


IT'S A THERMAL BLOCKAGE.

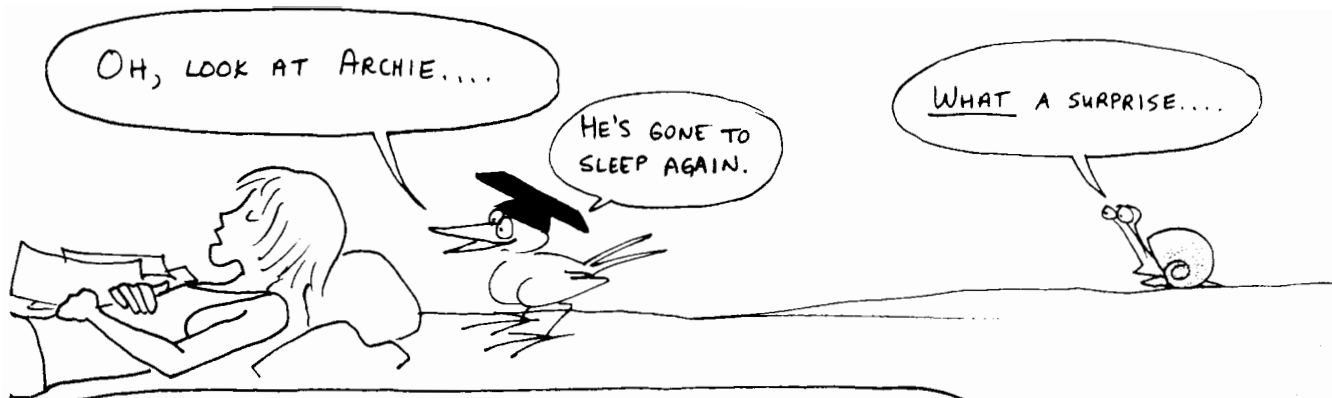
SO ARCHIE'S EXPERIMENT IS DOOMED TO FAILURE?



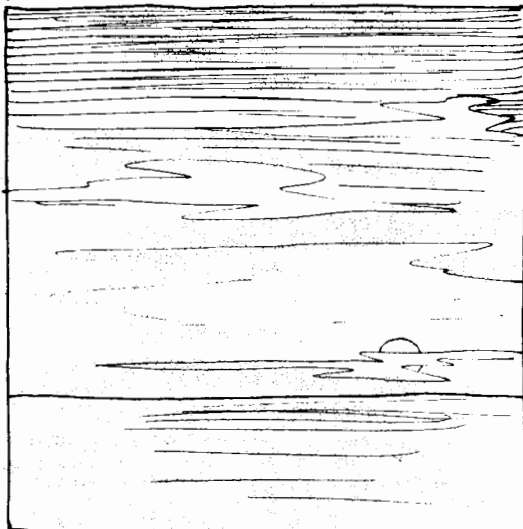
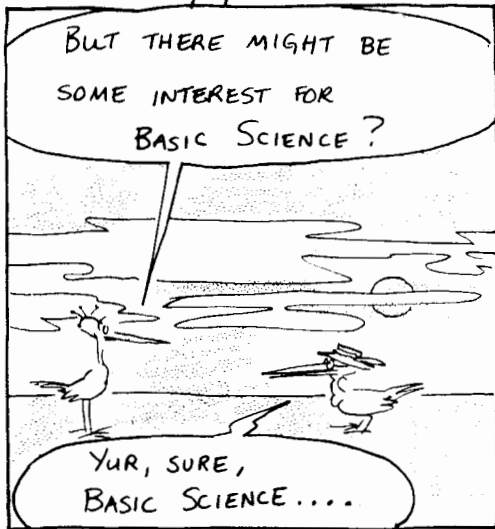
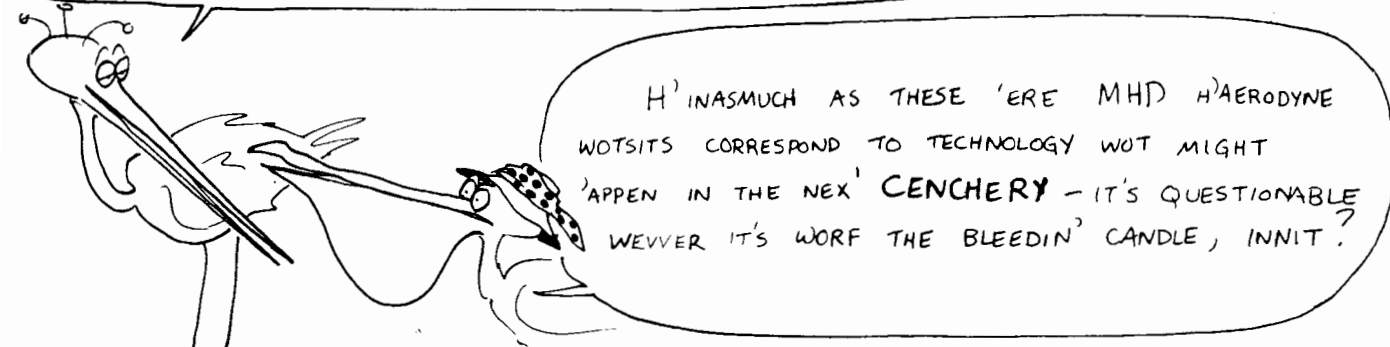
THAT'S NOT SO CLEAR. IT ALL DEPENDS ON THE ELECTRICAL CONDUCTIVITY OF THE AIR (AND THE VARIOUS WAYS OF AFFECTING IT). IF IT'S HIGH ENOUGH(*) THEN THE PRODUCTION OF HEAT WILL STAY MODERATE, AND THERE WON'T BE ANY BLOCKAGE.



(*) SEE APPENDIX E (PAGE 71)



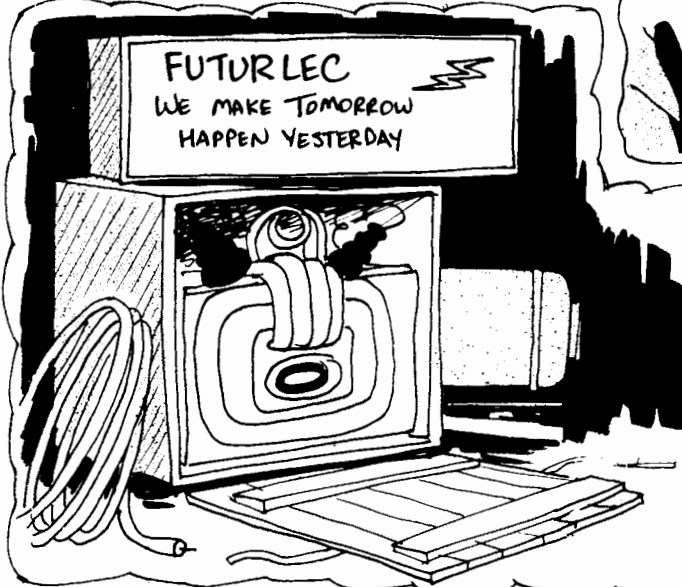
WHAT DO YOU MAKE OF ALL THAT?



ARCHIBALD'S DREAM



MR. HIGGINS? YOU ORDERED
A TWO-HUNDRED-MEGAWATT ELECTRICAL
GENERATOR, A TEN-MEGAWATT MICROWAVE
SOURCE, A REEL OF SUPERCONDUCTING WIRE,
TOTAL WEIGHT TWENTY TONS...?



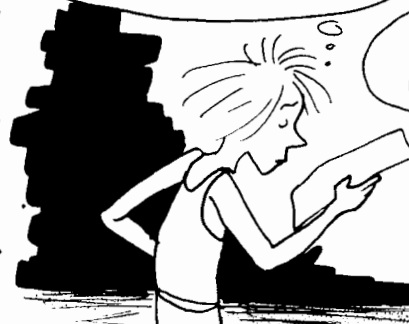
THERE'S SOME
SMASHING STUFF,
ARCHIE! WHEN DO WE
START?



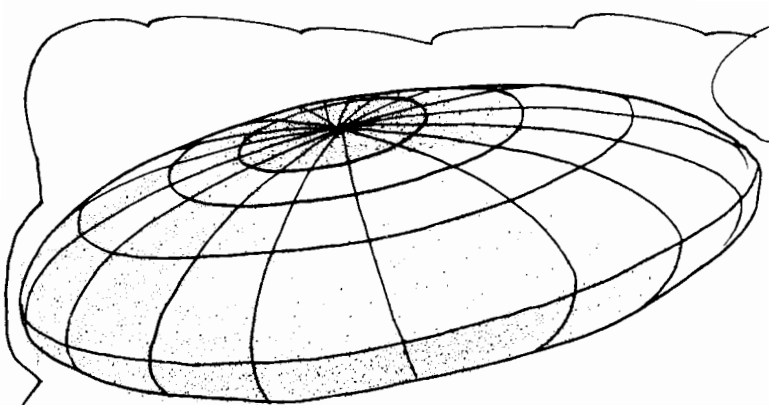
THAT WAS A WEIRD TRUCK HE HAD,
TIRESIAS. DID YOU SEE IT?



NEVER SEEN ANYTHING
LIKE IT! OH, WELL....



WE GO FOR IT?
WE GO FOR IT?



WHY IS YOUR AERODYNE SO SQUASHED?



IT'S A BETTER SHAPE FOR EXPLOITING THE DECOMPRESSION I'M GOING TO PRODUCE ON THE TOP AND THE COMPRESSION UNDERNEATH.

FIRST LET'S DEAL WITH THE MAGNETIC FIELD. USING THE SUPERCONDUCTING WIRE, I CAN MAKE THE CURRENT FLOW IN ALTERNATE DIRECTIONS, LIKE THIS.

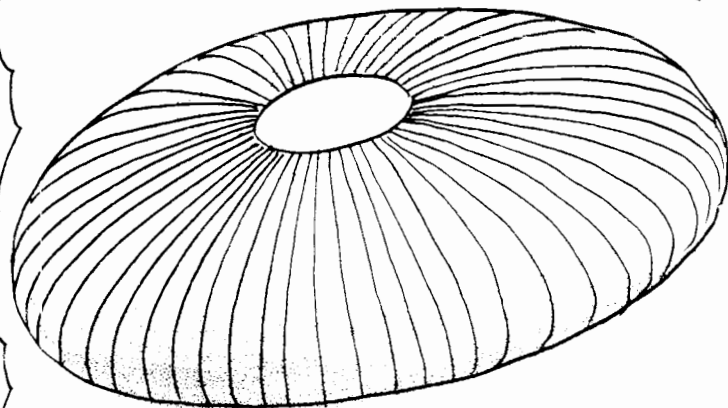
IN THESE PARALLEL WIRES, THE CURRENT REVERSES FROM ONE TO THE NEXT.

THE WIRES WILL BE COOLED TO VERY LOW TEMPERATURE WITH LIQUID HELIUM. \odot AND \otimes ARE VECTORS PERPENDICULAR TO THE PLANE OF THE DRAWING; \odot POINTING TOWARD THE READER, \otimes AWAY FROM THE READER.

YOU GET A MAGNETIC FIELD WHICH REVERSES EVERY 1 MILLIMETERS.

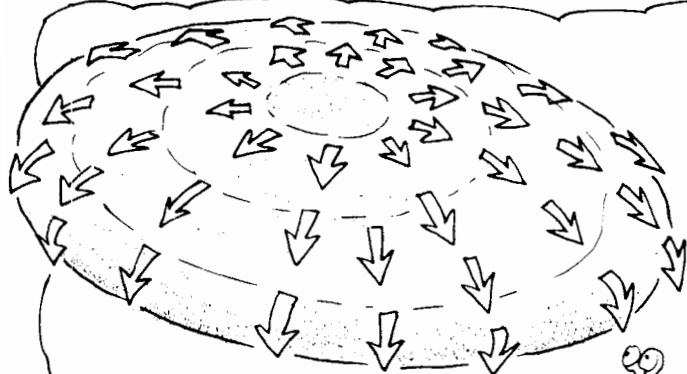
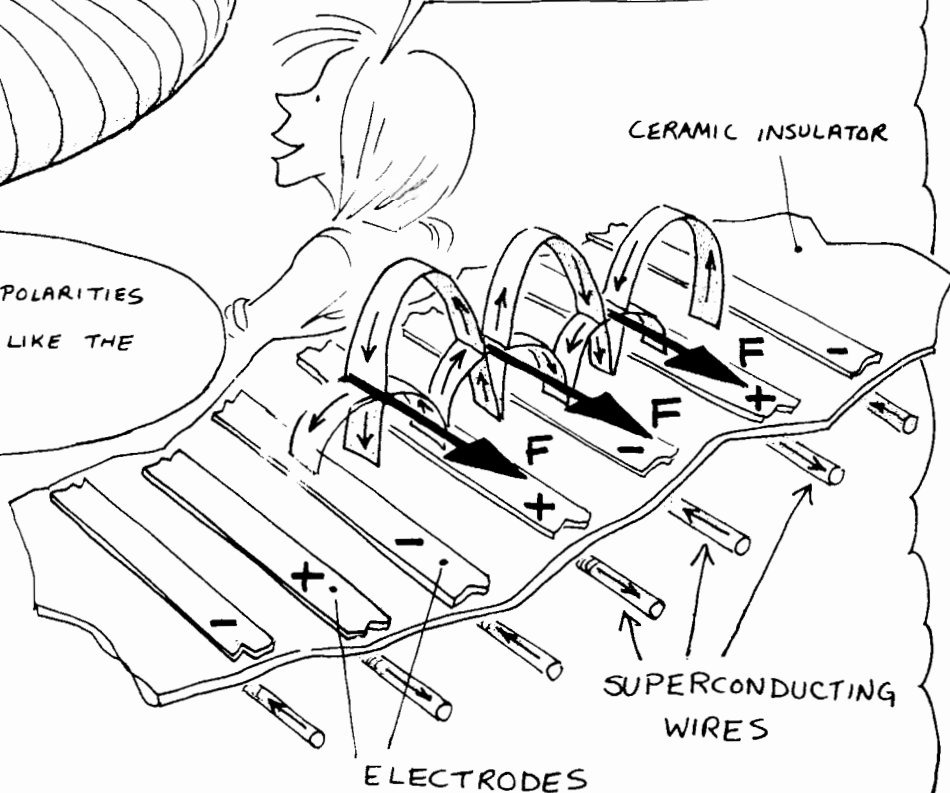
THE WIRES WILL FOLLOW THE MERIDIANS OF THE VEHICLE.

AND I'LL COVER THEM WITH THIN CERAMIC TILES.



OVER THE TOP OF THE TILES I'LL PUT THE ELECTRODES, ALSO ALIGNED WITH THE MERIDIANS.

AND YOU ALTERNATE THE POLARITIES OF THE ELECTRODES — JUST LIKE THE PARIETAL ACCELERATOR



THAT WILL CREATE THIS KIND OF FORCE FIELD AROUND THE APPARATUS.

I CAN PUT THE WIRES AND THE ELECTRODES VERY CLOSE TOGETHER, WHICH HAS SEVERAL ADVANTAGES.



FIRST, IT KEEPS DOWN THE VOLTAGE I
NEED TO APPLY TO THE ELECTRODES.

SECOND, IT KEEPS DOWN THE VOLUME IN WHICH THE
MAGNETIC FIELD IS CREATED. IN PRACTICAL TERMS,
THAT'S THE AREA OF THE SURFACE OF THE MACHINE,
MULTIPLIED BY THE SPACING BETWEEN THE WIRES.

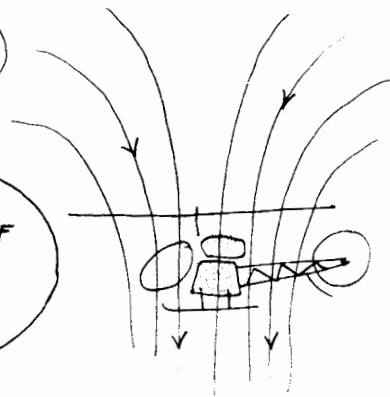
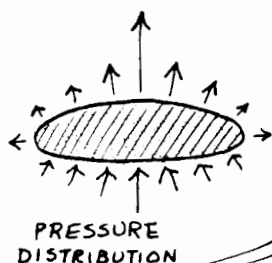
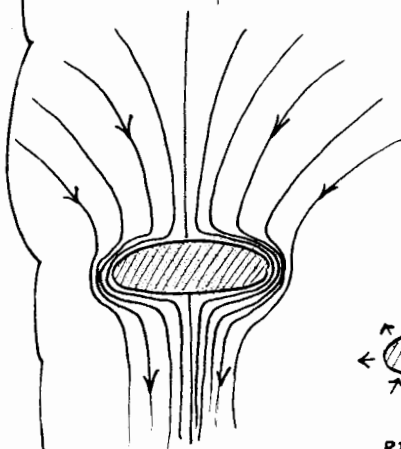
THIRD, THE ACTION TAKES PLACE IN A THIN
LAYER, CONCENTRATING THE IONIZATION, THE
FORCE.

AND HERE'S THE GASEOUS
FLOW THAT RESULTS.

IT'S LIKE A SORT OF
ELECTROMAGNETIC
HELICOPTER.

IT JUST REMAINS TO PRODUCE
ENOUGH IONIZATION, THAT IS, ENOUGH
FREE ELECTRONS IN THE LAYER OF GAS.

IF YOU PUT THE ELECTRODES A
MILLIMETER APART AND USE A THOUSAND VOLTS,
THAT SHOULD BE ENOUGH TO STRIP ELECTRONS
FROM THE ATOMS, FREEING THEM FOR
A CURRENT TO PASS.



THE IONIZATION PROBLEM

THE COMPONENT OF THE AIR THAT PROVIDES FREE ELECTRONS ISN'T OXYGEN OR NITROGEN, BUT NITROUS OXIDE (NO). BUT THE SIMPLEST SOLUTION IS TO ENRICH THE AIR WITH A SUBSTANCE THAT GIVES OFF PLENTY OF FREE ELECTRONS, SUCH AS CESIUM OR SODIUM.

SO WE BORE PORES THROUGH THE CERAMIC COVERING, AND EMIT SMALL QUANTITIES OF CESIUM VAPOR THROUGH THEM DURING FLIGHT.

ON BOARD, ARCHIE'S GOT A GENERATOR PRODUCING A VERY HIGH FREQUENCY ALTERNATING ELECTRIC FIELD IN THE SURROUNDING AIR (THREE THOUSAND MEGAHERTZ).

THESE MICROWAVES ARE RAPIDLY ABSORBED BY THE LAYER OF AIR SURROUNDING THE MACHINE AND ALSO PRODUCE FREE ELECTRONS.

LAYER OF
PLASMA

PATH OF A
MOLECULE OF GAS

IONIZATION

DEIONIZATION ACCOMPANIED
BY LIGHT EMISSION

RIGHT, I RECKON THAT'S THE LOT.
AN INTERNAL TELEVISION CIRCUIT, USING
MICROCAMERAS DISTRIBUTED OVER THE
SURFACE, WILL GIVE AS GOOD A VIEW OF
THE OUTSIDE.

T MINUS TEN
AND COUNTING...

WHAT'S THAT
GADGET?

IONIZATION!

IT'S LUMINOUS...
REDDISH....

STRIKE ME PINK! LENNY AND HIS
FRIEND, OVER THERE....

THEY'D BETTER LOOK
OUT FOR THE
MICROWAVES!

WE'D BETTER MOVE AS FAST AS WE CAN!

RAISE THE LANDING-GEAR!

CRAZY... IT FLIES
JUST LIKE A HELICOPTER.

!?

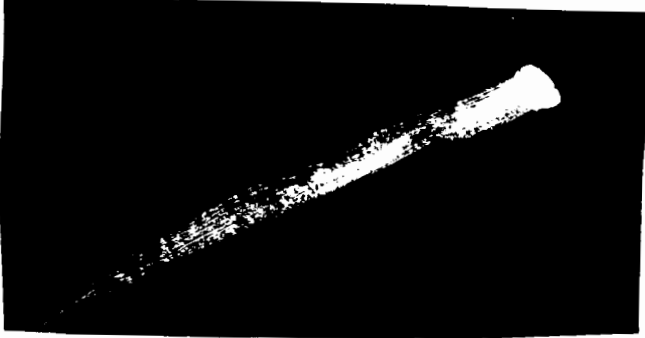
SOPHIE!

EXCEPT THAT INSTEAD OF
CHANGING THE ANGLE OF THE ROTOR
BLADES, YOU ALTER THE CURRENTS.

LOOK AT THESE TWO! WHAT'S HAPPENED TO THEM?
THEY LOOK LIKE THEY'VE SEEN THE DEVIL.

IT'S WEIRD.
THEY'RE TOTALLY ZONKED OUT....

THE MHD AERODYNE CONTINUES ON ITS WAY, LEAVING BEHIND A LONG, BRIGHT TRAIL OF CESIUM VAPOR.



PILE ON THE COALS!

THE POWER INCREASES, AND THE MACHINE ASSUMES THE ASPECT OF A SHOOTING STAR...

OH GOSH, WOW, GOLLY!
WE'RE GOING AT LEAST
FOUR OR FIVE TIMES FASTER
THAN SOUND!

HEY, ARCHIE... SINCE WE'RE CONTROLLING
THE GAS FLOW COMPLETELY, WE'RE
FLYING WITHOUT ANY TURBULENCE OR
SHOCKWAVES, RIGHT?

I GUESS,

ERGO... NO NOISE.

FIRST THERE'S THE SOUND
BARRIER... THEN THE HEAT
BARRIER... AND NOW, I GET
THE FEELING WE'VE BROKEN...

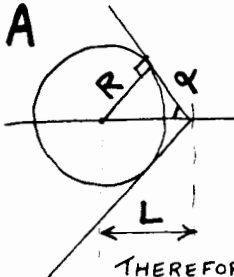


THE SILENCE BARRIER

THE
END

SCIENTIFIC APPENDIXES

A DURING A TIME t , AN EMITTED WAVE PROPAGATES RADIALLY TO A DISTANCE $R = V_s t$, WHILE THE OBJECT MOVES $L = Vt$.



THEREFORE $\frac{V}{V_s} = \frac{L}{R}$ SINCE $\frac{V_s}{V} = \frac{R}{L}$

B IT IS POSSIBLE TO ACT ON THE WAVE SYSTEM IF THE ENERGY RECEIVED BY THE VOLUME ELEMENT **JBL** (WORK DONE BY THE LAPLACE FORCE ALONG THE INTERACTION LENGTH) IS GREATER THAN THE KINETIC ENERGY $\frac{1}{2} \rho V^2$. IN SALT WATER ELECTROLYSIS LIMITS J TO 1 A/cm^2 (10^4 A/m^2). SUPPOSE $V = 8 \text{ CM/SEC}$. $\leftrightarrow 2 \text{ MM}$ ASSUME THE CYLINDER GOES 8 MM ($8 \times 10^{-3} \text{ M}$), WITH AN INTERACTION LENGTH EQUAL TO THE SIZE OF THE ELECTRODE: $2 \times 10^{-3} \text{ M}$; AND $\rho = 10^3 \text{ KG/M}^3$. IF $B = 1 \text{ TESLA}$ ($10,000 \text{ GAUSS}$) THE INTERACTION PARAMETER IS $S = \frac{2JBL}{V^2} = 10$. THE BOW WAVE IS ANNIHILATED....

C THE BOAT HAS A THRUST OF 1 GRAM. OR 10^{-3} KG OR 10^{-2} NEWTONS . IT TRAVELS AT 0.1 M/SEC , CORRESPONDING TO A POWER OF 10^{-3} WATTS . THE GENERATOR SUPPLIES 25 VOLTS, 20 AMPERES, THAT IS, 500 WATTS. THE EFFICIENCY IS THUS $\eta = \frac{10^{-3}}{500} = 2 \times 10^{-6}$. FLUID PASSES THROUGH THE ACCELERATOR IN TIME t . SO THE PROPULSIVE POWER IS $\frac{JBL}{t}$. BUT $\frac{1}{t}$ IS THE SPEED V . MOREOVER, THE POWER DISSIPATED BY THE JOULE EFFECT IS J^2/σ , WHERE σ IS THE ELECTRICAL CONDUCTIVITY. SO THE EFFICIENCY IS $\eta = \frac{JBV}{JBV + J^2/\sigma}$ WITH $\sigma = 10 \text{ MHOS/M}$
 $B = 25 \text{ TESLAS}$
 $V = 20 \text{ M/SEC}$
 $J = 10^4 \text{ A/M}^2$ THE EFFICIENCY INCREASES WITH V .

WE GET
 $\eta = 0.33$

D THE EXCESS PRESSURE AT THE STATIONARY POINT WILL BE, IN ALL, $\frac{1}{2} \rho V^2$, WHERE ρ IS THE DENSITY OF THE AIR (1.3 KG/M^3) AND V IS THE SPEED OF THE OBJECT. FOR A FRONTAL AREA OF 1 M^2 , THE POWER P LOST IN THE WAVE TRAIN WILL BE $\frac{1}{2} \rho V^3$.

IF $V = 600 \text{ M/S}$ $P = 200 \text{ MW}$
 IF $V = 1500 \text{ M/S}$ $P = 2000 \text{ MW}$

E THE POWER ASSOCIATED WITH MHD ACCELERATION IS **JBV**. WITH $J = 10^4 \text{ A/M}^2$, $B = 4 \text{ TESLAS}$, $V = 1000 \text{ M/SEC}$, WE HAVE $JBV = 40 \text{ MW/M}^3$. IF THE ELECTRICAL CONDUCTIVITY OF THE AIR (AWAY FROM EQUILIBRIUM) REACHES 10 MHOS/M , THAT OF SALT WATER, THEN THE HEAT J^2/σ PRODUCED BY THE JOULE EFFECT, CORRESPONDS TO A POWER OF 10 MW/M^3 . IT'S ATTAINABLE. IT WOULD BE BEST TO WORK WITH B LARGE (20 TESLAS) AND TO INCREASE ARTIFICIALLY THE CONDUCTIVITY σ (BY EMITTING ALKALI THROUGH A POROUS WALL OR VIA THE ACTION OF MICROWAVES).

